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An Econom
Analysis of the Impact of Oil Prices on Urban Structure

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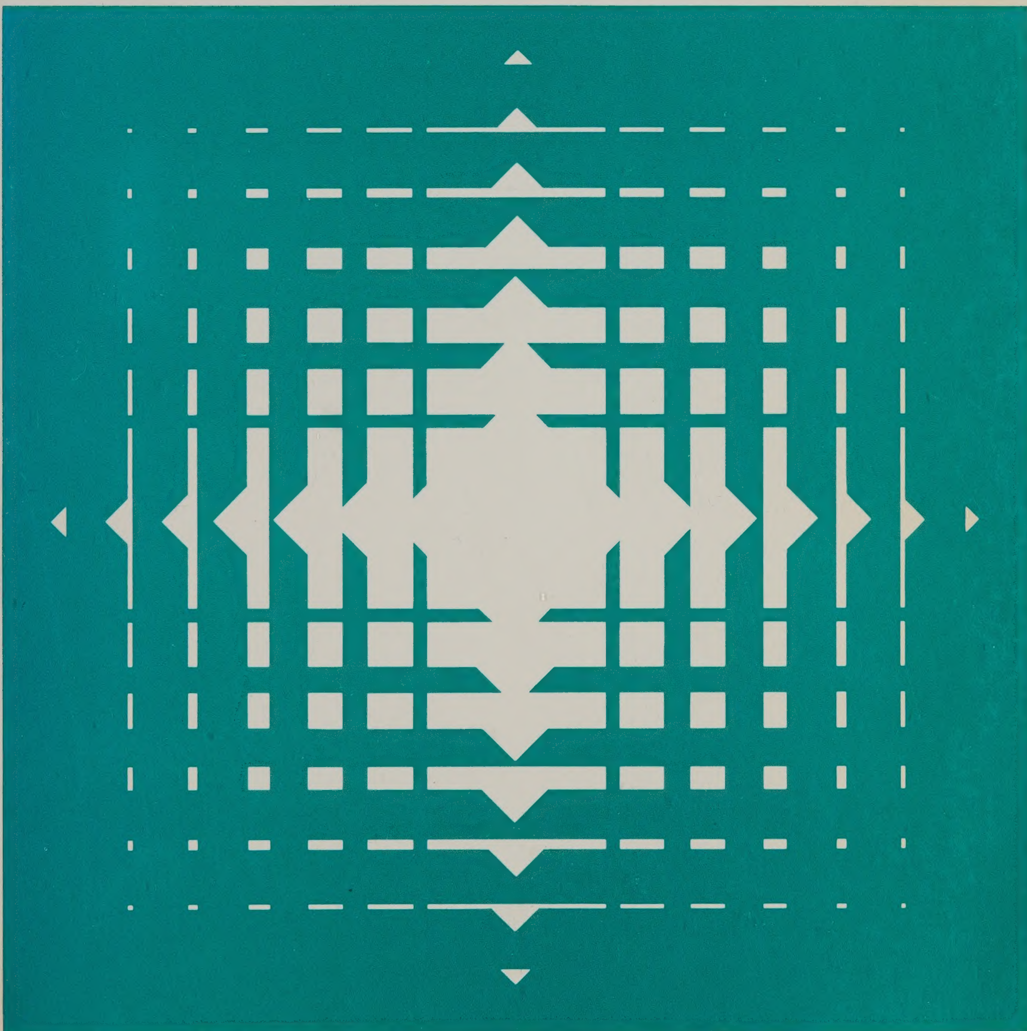

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AN ECONOMIC ANALYSIS OF THE IMPACT
OF OIL PRICES ON URBAN STRUCTURE

1
Introduction

Perhaps the most striking economic feature of the last decade has been the rapid and very substantial increase in the price of crude oil. Because of the pervasive influence of petroleum and its related products in the economy – we are certainly at present in the Petroleum Age – these price influences have literally affected all individuals and economic units to some degree. While many have benefited – owners of petroleum resources in particular – the majority of individual consumers and firms have seen their economic lives disrupted in a manner they consider undesirable. The purpose of this study is to investigate some of the ways in which a substantial proportion of the residents of Canada, the urban population, is affected and will be affected by the increase in petroleum prices.

As is the case for any substantial economic shock that is expected to be more or less permanent, both short-run and long-run effects are likely. The short-run effects for urban residents will be essentially the same as those affecting any Canadian citizen. Individual consumers will find prices for gasoline and heating oil substantially increased and will be forced to make some adjustment in spending habits to avoid accumulating debts. Individuals either will have to find some way to conserve on these higher priced petroleum products or will have to forgo expenditures on other items. In the same manner, firms, when faced with higher prices for hydrocarbons to be used either as fuels or as intermediate products, will have to substitute some less expensive input or pass along the higher input prices in terms of higher prices for their outputs. If product price increases are the solution, firms would expect to experience a drop in sales and a reduction in profits.

For urban residents in particular there may well be longer-term structural changes, which may have even more importance for their economic well-being. When faced with higher gasoline prices, commuters may decide to give up their homes in the suburbs and move to locations closer to their place of employment.

Such a shift could substantially change both the population density of urban areas and the structure of rents and house prices. Alternatively, suburbanites may decide to adopt other modes of travel than by car, such as rail or bus, or they may decide to conserve fuel by driving more fuel-efficient automobiles. Such shifts could have important implications for the public transit systems and for urban policy on streets and freeways. Similarly, firms may see advantages to relocating their operations as a way of either avoiding higher transport costs for their products or obtaining an advantage in labour markets by moving closer to potential employees. Again, the consequences for the structure of the city are apparent.

The principal concerns of this study are these longer-term structural changes for urban areas, which increases in the price of petroleum might be expected to generate. Reasons for the importance of the direction and magnitude of such changes are easy to identify. It is clear, for example, that a shift in population towards the central business district will have significant implications for policies on zoning, the provision of public services such as parks, and the locations of schools and other public facilities. A significant shift to bus and subway ridership and a reduction in the use of automobiles for travel to work will have important implications for policy on public transit and the provision of parking. Plans for road rebuilding and the provision of expressways cannot be properly formulated without information on the expected travel mode of the commuter. Substantial shifts in industry from the central city to the suburbs will change employment opportunities in both places and will thus have implications for transportation policy.

Of course the short-term and long-term effects identified above are in no sense independent. Indeed, in many cases it is precisely the short-term choices made by individual consumers and producers that, taken together, determine the long-run structural changes. Thus the individual's decision to conserve energy by taking the subway will, in the long run, influence the development of alternative modes of travel. Individual choices between moving and buying smaller cars will have a fundamental impact on the density and structure of the city. Thus, while our concern is with these long-run structural changes, it is only through an understanding of the underlying behaviour of individual economic units that we can hope to understand and explain the longer-term effects.

Another interaction between the long-term and short-term responses to energy price increases that is important relates to the speed of price adjustments. Suppose, for example, that consumers and firms make decisions on the basis of current prices and substantially discount expected future price increases. For short-run decisions this is, of course, the appropriate procedure, and most consumer decisions are short run in nature. Consumers would not switch from cars to the transit system because they expect the future price of gasoline to be

higher; nor would they be expected to buy smaller cars today in anticipation of higher gasoline prices tomorrow. And while the purchase of a house is generally seen as a long-term decision, the decision of where that house should be located is much more short run in nature. Homeowners are able to switch locations reasonably easily, although such switches may well have cost implications. Thus, in situations where micro-economic decisions are heavily influenced by current prices, short-run adjustments may result in changes that have undesirable long-run implications or may result in incorrect signals to policy-makers.

Consider, for example, an urban area where considerable growth is taking place owing to income increases and population growth. Further, suppose that it is known almost with certainty that gasoline prices will rise at some specific time in the future. Consumers, by continuing to drive to work in increased numbers, will signal policy-makers that more expressways to the city centre and more parking lots are required. They will also anticipate the need for more schools and recreational facilities in the rapidly expanding suburbs. A policy of providing such public goods may be quite inappropriate, however, if after the price rise in gasoline takes place there is a significant shift in residence location from the suburbs to the central city. Obviously, if the public officials had anticipated such a structural change, the policies on roads, schools, and so on would have been quite different. Indeed, it might have been optimal to puruse policies to encourage such a structural change before the fact of the energy price rise.

It should be emphasized that the difficulty just described is not fundamentally a difficulty associated with the inability or unwillingness of public officials to make appropriate policy decisions when faced with information about future structural changes. The principal problem is that the expected structural changes associated with energy price increases are simply not known. Faced with uncertainty about the expected structural changes that would accompany known future energy price increases, one conceivable policy would be to move the price changes forward through a system of energy-use taxes. This action would 'reveal' the correct underlying model and would, to some extent at least,[1] limit the extent of fundamental policy errors.

The difficulties associated with the timing of petroleum price increases are particularly relevant for the Canadian economy. Federal government policy has

1 Problems would still exist, however, owing to the fundamental adjustment problems associated with structural change. Some adjustments would occur quite quickly and others more slowly, and at any point in time it would be difficult to determine whether or not equilibrium had been achieved. Note also that the kind of tax suggested here would have to be nation-wide, or at least province-wide, since otherwise intercity or interprovincial distortions would be created.

been designed to deliberately slow down the adjustment of energy prices to their equilibrium levels – just the opposite of the suggestion made above. In so far as urban policy-makers are unable to accurately predict the long-run structural changes, current oil pricing policy not only increases the difficulties faced by urban policy-makers but also almost guarantees that long-term policies will be pursued today that will be quite inappropriate tomorrow. Such inappropriate policies may simply be doing nothing now when in fact the future, were it known, would dictate the encouragement of fundamental structural shifts. The importance of such errors is not reduced by their passive nature. It is clear then that the identification of the changes that energy price increases are likely to generate in the urban structure is particularly important for Canada, where difficulties of adjustment have been exacerbated by government policy.

Equally as identifiable as the importance of such structural changes are the difficulties of predicting what the changes will be. Some of the possible reactions to price changes have policy implications opposite to others, and it is very difficult to make a persuasive case for one model relative to some alternative. Indeed, this study does not purport to 'solve' the problem of exactly how higher petroleum prices will affect urban structure but is confined to identifying the principal consequences, in terms of structural change, of the various options open to economic units. As will become clear, the problem is not so much one of identifying which theory is the correct one as it is one of identifying which of the preferred explanations will be more important determinants of the final outcomes. The theories, or explanations, of urban structural change are not mutually exclusive, and to some extent all will be true in the sense that all will provide part of the explanation for the final outcome.[2] Of course with a sufficiently rich data set one could empirically distinguish among and calculate the contributions of the various explanations. Unfortunately much of the information that would be required for such tests is unavailable.

The theoretical difficulties associated with identifying 'the' model stem from a number of sources. First, the analysis will be conducted in terms of a representative city, in order that the results derived will have the broadest possible application. At the same time it is clear that cities vary widely in many important characteristics, and an explanation that might be quite appropriate for one may be unacceptable for another. A persuasive theory to predict a significant shift from car use to public transit could be developed for Montreal or Toronto where efficient rapid transit systems exist. The same theory might not be convincing for Vancouver or Calgary. The reasons that one observes quite different urban structures, even for cities of approximately the same size, is of

2 And of course there may be other explanations of which we are unaware.

obvious interest in terms of this study, and the subject is taken up in more detail in Chapter 2.

Another theoretical difficulty is associated with the fact that a variety of behavioural assumptions about households and firms are possible, often with quite different implications for urban structure. An outline of these arguments is presented in Chapter 3. Theoretical models of aggregate behaviour, however, particularly models designed to permit empirical testing, simply cannot encompass such diversity. Indeed, as will be seen in Chapter 4, which reviews the theoretical literature, a principal assumption in the standard urban model is that individuals have identical utility functions.[3] Individuals are allowed to differ, if at all, only with respect to endowments or income. As a consequence, any attempt to provide a theoretical explanation of an urban area must abstract from differences among individuals; differences that in practice must be important in determining the structure of an urban area. In Chapter 6 an attempt is made to identify the range of possible structure implied by alternative theoretical specifications by simulating some very simple and specific versions of the various models.

Another difficulty with the standard urban model is that some of the choices facing consumers confronted by higher energy prices cannot be formally included. Standard models allow the individual to reduce travel costs only by moving closer to the CBD. Substitution, either towards smaller and more fuel-efficient cars or towards other modes of travel, cannot be easily considered. Chapter 5 takes an initial step in the direction of allowing such substitutions by formulating two somewhat more general models. As would be expected, this extra generality is not without cost. Another form of substitution that can be observed is substitution of location for firms and individuals, not within cities but among urban areas. Higher oil prices and the resulting increase in the wealth of the oil-producing provinces, for example, have clearly resulted in a westward shift of economic activity. Although these kinds of changes are difficult to model, some preliminary comments are included in Chapter 3.

Of course not all the difficulties associated with identifying the crucial parameters that will determine urban structure are theoretical. First, in many instances the required data are simply not available; for data have traditionally not been collected on a city basis. Furthermore, those studies that have been done, some of which are reviewed in Chapter 7, are often of only peripheral interest in terms of urban structure. This fact is due to both the data availability

3 Of course this assumption is not unique to the urban literature. It is widely used in international trade theory (where it is generally not needed) and underlies the construction of fundamental macro concepts such as the consumption function.

already referred to and the fact that appropriate theoretical models to address these issues have not been developed. For these reasons little direct empirical evidence can be brought to bear on the central issues of concern in this study. As a second-best solution, Chapter 6 presents several theoretical simulations using standard functional forms. These simulations provide some indication of what the range of effects might be when one or another of the theoretical models is assumed to hold.

Chapter 8 provides a brief summary of urban structure in Canada, paying particular attention to the energy-use profile of Ontario and Toronto. Chapter 9 outlines the policy implications and presents some brief concluding remarks. The purpose of this chapter is to identify the kind of policies that could be seen as appropriate for the range of models described elsewhere and give some idea of which policies would be preferred under uncertainty about future changes in urban structure. The purpose is therefore not to advise urban policy-makers on precisely what actions should be undertaken, but rather to identify policies appropriate for a variety of scenarios and for different cities. This chapter will also include a discussion of appropriate goals for urban policy-makers and the policy tools that would be most effective in achieving the goals.

2
An economic explanation of urban history

There are many elements that influence the formation of urban areas and are important determinants of their structure and form. The theoretical literature that will be considered in Chapters 3 and 4 emphasizes the roles of variables such as land rents and distance and household income and preferences. To remain tractable, however, such models must abstract from features such as the physical geography of the location and the historical development of the community. These latter characteristics are much more difficult to deal with in a systematic fashion, because there are no norms about which general propositions can be constructed. All cities differ to some extent, and often significantly, in terms of historic development and locational characteristics, and thus a description of such influences must take a rather taxonomic form – an approach that does not find favour in the economics discipline. These influences may nevertheless be quite important both for an understanding of the present and for an appreciation of how future changes may occur. This chapter will provide a brief description of such factors, the main emphasis being on the economic explanation of historical differences in urban formation.

The physical landscape in which urban areas develop has an obvious influence on their structure and density. Cities like Vancouver are constrained on one side by the ocean and on another by the mountains, and, as one would expect, they have a high population density in the city centre. Similarly, Toronto and Montreal are restricted in development more than Winnipeg and Calgary and are correspondingly more dense, even when population differences are taken into account. Reasons for the differences are, of course, easily identified. Consider two cities with the same population and the same initial density, one having the Central business district (CBD) on a natural barrier such as a lake or an ocean. This restricted city will require a longer journey to work for the average commuter than a circular city will. Thus in constrained cities there will be higher

demand for residential locations near the CBD, which in equilibrium will result in higher rents and higher densities.

A much more subtle explanation of the development and structure of cities argues that the period in history in which growth took place is the principal determinant of present-day structure and density. It is argued, for example, that before the second decade of this century, when the automobile became a common means of conveyance, the common mode of transport was by foot, except for those well-to-do who could afford horse-drawn carriages. In such circumstances cities were small, seldom more than two or three miles in diameter, since most workers had to walk to their place of employment. The advent of the car along with the increases in incomes that made their purchase possible allowed individuals to move farther from their workplace. More increases in incomes and improvements in transportation facilitated the 'flight to the suburbs.'

An additional feature of this explanation is the assumption that once residential construction has taken place little change occurs. Harrison and Kain (1974) have argued that demolition and rebuilding of new residential structures is uncommon and is not a large component of new housing space, perhaps 10 or 12 per cent of the total. Thus at any point in time the structure of a city is mainly a function of past development. That part of a city that developed during periods of modest income increases and/or poor transportation facilities will tend to be dense. Cities or sections of cities that developed in times of rapidly rising incomes exhibit 'urban sprawl.' In general, then, one would expect to observe that older cities permit higher population densities near the CBD than cities of more recent origin do.[1]

This explanation of the structure and density of cities was first advanced by Harrison and Kain (1974). Their model considers the density of an urban area at any point in time as the sum of the densities of development in each time period weighted by the amount of growth that took place at the time. In their initial formulation of the empirical model they use as dependent variable the proportion of new single-family dwellings in total new residential construction in each time period as a proxy for incremental residential density. The explanatory variables are a time trend to represent changes in transportation costs and incomes, and the size of the urban area.[2] The model was then used to estimate

1 Of course density is not determined entirely by structures. Density can be increased by crowding and by subdividing older houses, and this has often occurred. Similarly some city areas may have significantly lower densities than the structures would permit.

2 There is an observed positive relation between city size and city density.

density gradients for eighty-three metropolitan areas for ten time periods, and the results were compared to density estimates that had been derived earlier, using the more traditional urban models, by Muth (1969), Barr (1970), and Mills (1970). Harrison and Kain argue that their estimated density functions seem to be generally consistent with the earlier estimates and in some situations seem to conform to reality somewhat better. This, they contend, lends support to their approach.

A systematic analysis of Canadian cities along Harrison-Kain lines does not seem to have been attempted. This may be in part due to the lack of large cities to be used for comparison, or because Canadian cities do not have as much 'history' as those of the United States. The evidence that one finds in the Canadian literature tends to be fairly descriptive. Various authors, however, have commented on the importance of history in the determination of Canadian urban structure. For example, MacKinnon (1974, 243) concludes that 'There is ample empirical and theoretical evidence that the form of the city is in large degree the cumulative product of past and current transportation system configurations and technologies.'

There are several other arguments in the urban literature relating to the importance of the historical increase in accessibility brought about by the increase in private motor vehicle ownership. One common theme is that the suburbanization of households has also resulted in a suburbanization of industry as industry relocates in areas close to an available labour supply. Moses and Williamson (1967), however, turn this argument around and suggest that the principal reason for reductions in residential densities was the advent of the truck, which, by removing the reliance on rail and water transport, permitted industry to move to the suburbs. Households then followed industry, and population decentralization resulted. Whatever the reason for the shift of industry to the suburbs, the importance of the phenomenon cannot be denied. Kain (1968) has shown that for the United States in 1963 over half of all manufacturing employment, approximately one-third of all service and wholesaling employment, and just less than half of all retail employment in the forty largest US cities were located in suburban areas outside the central city. In such circumstances one does not want to rely exclusively on models that assume that all work-related trips are to the CBD.

The historical explanation of the structure of urban areas has important implications for the effects of increases in the price of petroleum products. The implications of this theory are that energy price increases (or anything else) will have little effect on the existing city, and any effects that price changes would have would be largely confined to the newly developing periphery. Furthermore, if one accepts the arguments advanced by Kain (1979) that automobile ownership and increases in per capita incomes are the principal reasons for the lower

density developments that have been observed over the last century, then there may be little effect on structure at all. As Kain (1979, 29) has observed, 'Since both car ownership per capita and per capita disposable income are expected to continue to increase over the next 20 years, there is little or no reason to expect the dramatic changes in lifestyles and urban development patterns advanced by many commentators.' These issues will be taken up again in Chapter 5.

The purpose of this brief chapter has been to summarize an economic argument that suggests that the principal determinant of the future structure and form of urban areas is the economic climate that existed when the cities developed. The arguments in the remainder of the study rely on comparative static and dynamic changes in urban structure that oil price changes are expected to generate. In evaluating the results one must keep in mind that any conclusions must be tempered by the inherent inertia of an urban area.

3
The theoretical issues

INTRODUCTION

In Chapter 1 it was observed that when micro-economic units (individuals or firms) are faced with higher prices for petroleum products a variety of responses can be observed. The purpose of this chapter is to catalogue and describe the most important of these reactions and lay the groundwork for a more formal treatment of the models in Chapters 4 and 5. Five types of reactions will be described: residential location changes by consumers, industrial location changes by firms, substitution among transportation alternatives by consumers, substitution to reduce heating costs by consumers, and substitutions among other commodities by consumers. In each case it is assumed that only the specified change takes place and all the other effects are absent.

Note that the methodology here is a kind of theoretical experimentation. Parameters in the model thought to be important in determining urban structure are varied, one at a time, and the implications are examined. It is recognized, of course, that in practice some or all of the reactions may be occurring at the same time. But while from a theoretical point of view it is often possible to identify responses resulting from changes in one variable, it is almost never possible to reach unambiguous conclusions when all variables are allowed to vary simultaneously.[1] It is to be hoped that when the separate results from the various models have been derived, a consensus result can be found by aggregation, but often even this is not possible.[2] If one can define a weighting scheme for the

1 Empirical analysis is often able to identify the influence of several variables and to evaluate their relative importance.

2 Aggregating the results from several models, each of which has investigated the effects of a single variable, generally will not take account of interactions among variables. These interactions may be very important.

variables, the possibility of obtaining definite results is sometimes improved, since in some situations a dominant influence can be identified. The point to be kept in mind is that the individual models described here and in Chapters 4 and 5 should be thought of as complements, not as competing explanations of the determinants of urban structure. The specific models with their restrictive assumptions are not individually proposed as explanations of the 'real world,' but rather should be seen as attempts to identify the influence of specific factors thought to be important determinants of urban structure.

THE DETERMINANTS OF CHANGE

In this section five mechanisms through which increases in petroleum prices would be expected to influence the behaviour of urban residents will be considered. In each case it is assumed that all other things are constant in order to highlight specific cause and effect relationships. In the next section the implications of each of these five mechanisms for urban structure will be summarized.

Residential location

It is assumed that the principal income earner of each household travels some distance from his residence to his place of employment. The cost of this travel is assumed to be directly related to the cost of gasoline. When faced with gasoline price increases one option open to a householder is to reduce the cost of travel by relocating his residence closer to the place of employment. This is the principal motivation underlying the journey-to-work model, which will be described in more detail in Chapter 4. Here it is sufficient to note that in this model the householder is seen to trade off space, which decreases in cost per unit with distance, and travel expenses, which increase with distance. An equilibrium is achieved when the marginal savings associated with moving further from the CBD in order to pay lower rents is just equal to the extra cost in terms of travel that such a move would entail.

Granting this tendency, there remains the question of what the short-run and long-run consequences would be. In the short run the desire by households to move closer to the CBD will put pressure on the housing market, and rents and house prices would be expected to rise near the CBD and fall in the suburbs. Vacancy rates would be expected to fall near the CBD, and there would be some tendency towards increasing the occupancy rate of existing structures. In the short run, however, there is limited scope for density changes. Most of the increase in demand for housing units near the CBD would be reflected in higher house prices and rents.

The long-run effects depend crucially on the long-run elasticity of supply of housing space. This is an empirical issue, and some of the relevant literature is

reviewed in Chapter 7. In general, very little price response on the supply side has been identified, and the principal determinants of demolition and rebuilding appear to be the age and condition of the dwellings. As has already been suggested, the main source of new dwelling units is new construction, most of which takes place in the undeveloped areas in the periphery. The initial impression, then, is that in so far as petroleum price increases increase the demand for housing closer to the CBD, most of the increase in demand in both the short and long run will be reflected in higher rents and house prices, with only modest effects on density.

The increase in demand for housing units and the corresponding reduction in demand in the suburbs would also be expected to increase the slope of the bid rent curve for the household sector. Increasing the slope of this curve will increase the savings associated with movements by households away from the CBD, and this increase in savings will tend to offset the inward movement described above.[3] Indeed, the net effect may be a movement towards the suburbs for some individuals.

Finally, note that the model employed here implicitly assumes that all journeys to work are to the CBD. It has already been observed that a substantial migration of industry to the suburbs has taken place since the Second World War. Thus only if it can be assumed that the majority of workers live further from the CBD than from their place of employment will reduction in the journey to work have unambiguous implications for the structure and density of an urban area.

Industrial location

There are at least three reasons why firms would consider relocating when faced with higher gasoline prices. The first and most obvious reason relates to changes in transportation costs. Suppose an initial situation where a firm located in the CBD is maximizing profits with respect to all variables, including location. An increase in transportation costs brought about by a gasoline price increase will affect the firm in two ways: costs of bringing intermediate inputs to the firm will rise, and costs of transporting the final product to the market will rise. If both outputs and inputs are transported by truck to and from destinations outside the urban area, then it is quite possible that a move to the suburbs would reduce transportation costs and increase profits. If rail or water transport is important for either inputs or outputs and the major rail and water terminals are in the CBD, the possibility that a move to the suburbs would be cost saving is less likely but still possible. The various combinations of transport facilities and relative importance of the costs of inputs and outputs defines a wide range of possibilities. It is

3 Such effects are considered in more detail in Chapter 4.

even possible that a firm located in the suburbs would find it cost efficient to move to the CBD to take advantage of relatively cheaper rail transport.[4] Thus any significant gasoline price increase would be expected to result in a new spatial equilibrium for firms, with an expectation that most moves would be outward from the CBD, owing to the present-day importance of truck transport.

In any initial equilibrium firms will have located in an urban area so as to minimize costs, given the rent gradient they face and their individual demands for space. A gasoline price increase would be expected to increase the slope of the rent gradient, and firms with heavy space demands may find it profitable to move to the suburbs to take advantage of relatively lower rentals. Such moves, of course, will reduce the upward pressure on rent by reducing the number of firms in competition for space. The final long-run equilibrium rent gradient will depend on the sensitivity of firm location to transportation costs.

A third possible reason for relocation relates to the transportation costs of the factor labour. Unlike other inputs, labour is asked to bear the cost of transporting its services to the production location.[5] In a free market situation labourers would be willing to accept a lower wage at locations less distant from their residence as long as savings in personal transportation costs were at least equal to the reduction in earnings. Thus with free labour markets, by pursuing their profit maximizing goals firms would locate in a fashion that would also tend to be welfare maximizing for households.

It is important to note that any institutional features that restrict the freedom of labour markets, such as minimum wage laws or labour union contracts, may well be harmful to firms, to individual workers, and to society as a whole. Suppose, for example, that because of some institutional rigidity a firm is required to pay the same wage for a particular job regardless of where in the urban area the firm is located. Any incentive for the firm to locate in a manner that would minimize workers' transportation costs would thus be completely removed and locational decisions would be based entirely on the transport costs of non-labour inputs, outputs, and the rent gradient. Furthermore, individual workers would be required to bear the cost of the misallocation, since they

4 Another possible response to relative changes in transportation costs could be switches to more (or fewer) plant locations in order to serve a dispersed market more efficiently. This response will be more likely with constant returns to scale in the production process.

5 This may be true to some extent for other factors of production as well. Thus the supplier of an input may be forced to absorb some or all of the transport costs of moving that input to the final demander. The incidence of transport costs will depend on bargaining strength, competition, and other factors, but in general would be assumed to be shared between buyer and seller.

would be required to pay the full increase in the labour transportation cost associated with the gasoline price increase.[6] Potential net urban output would be reduced because of the resources utilized in providing unnecessary transportation, and thus social welfare would not be maximized. Of course, as suggested in the previous section, householders may be able to reduce this cost by locating closer to their place of employment. Certainly situations will exist, however, where substantial social savings could be enjoyed by having a single firm move rather than by having many individual households relocate. It would thus seem important to encourage free labour markets if a spatial optimum is desired.

Transportation substitution

From the individual worker's point of view an alternative to reducing transportation costs by reducing distance travelled is to reduce costs per mile and leave distance unchanged. In general this object could be accomplished in one of two ways: by shifting to a more gasoline-efficient automobile, or by shifting to a cheaper mode of transportation – from a car to a bus, for example. Considerable evidence suggests that this is and will continue to be one of the more important reactions to energy price increases, and this literature will be reviewed in Chapter 7. Indeed, authors such as Kain (1979) have suggested that the compulsory fuel economy standards alone may be sufficient to offset the effect of higher gasoline prices for the typical commuter. Nevertheless the existing theoretical models do not allow for the possibility of these kinds of substitution, and in Chapter 5 some preliminary models that allow these possibilities will be formulated.

It is important to note that the two types of substitution described above are generated by substantially different models. Substitution towards a smaller, more fuel-efficient automobile can be explained only if the model contains an explanation of why large inefficient automobiles were preferred in the first place. The reason presumably is that the services of automobiles directly enter the utility functions of individuals, and that larger or more powerful cars are seen to provide more of the desired service. A shift from automobiles to some other travel mode, in contrast, while perhaps determined to some extent by differences in the quality of service, would seem to be mainly a function of travel time and convenience of the alternative travel modes. The major reason for the preference of automobiles over buses seems to be that cars are faster and provide more flexibility. Only when the benefits of these attributes are outweighed by the

6 This argument is less relevant for situations where workers take public transit to their place of employment. Even in this case, however, one would expect higher petroleum prices eventually to result in higher fares.

higher cost of gasoline will a switch to bus travel take place. Note that this argument does not apply to switching to more fuel-efficient cars, since the time and convenience cost of such a switch is presumably very small.

Heating costs

The discussion above is entirely in terms of the higher costs of travel that would be associated with increases in petroleum prices. Petroleum price increases have much more pervasive effects on society, however, and in fact a number of effects could dominate the increase in the costs of the journey to work. Most significant among these will be the effects on home consumption of energy, the most significant element of which will be home heating. Indeed, the average Canadian household spends four to five times as much on home heating as it does on gasoline for travel to work.

Of course the fact that heating costs are a much larger fraction of household expenditure than commuting costs are does not imply that heating cost changes will have as much influence on urban structure. Certainly the effects are not as well documented, nor have models been developed to explain possible effects on urban density and structure.[7] Several kinds of possible effects can be identified. First, it is clear that total heating cost, other things being equal, is a positive function of living space. Thus one method of conserving on energy would be to move to a smaller house or apartment. On the assumption that houses become larger as one moves away from the CBD and that apartments are concentrated near the CBD, such relocations would increase the slope of the rent gradient and a denser central city would result.

Giving up living space to conserve on energy is by no means the only alternative, however. Structures can be altered through insulation, and a more judicious use of available energy can be undertaken to reduce costs. Two general approaches to this sort of conservation are possible: one can make one's present residence more efficient, or one can move to a more energy-efficient residence. It seems clear that the most efficient method of producing an energy-efficient structure is to build it that way in the first place; and thus as energy prices rise, one would expect to find the most energy-efficient dwellings in the newer suburbs. It also seems probable that older houses are more difficult to insulate than newer ones, and certainly it is more difficult to improve the heating efficiency of apartment space than of single family homes. This would suggest that decisions to retain the same space and conserve by improving energy efficiency would result in a shift towards the suburbs. Note that it is entirely

7 One exception is Romanos (1978). His contribution is discussed in Chapter 4.

possible that the cost savings in moving to a new, energy-efficient house in the suburbs could more than outweigh the additional commuting costs such a move would entail.

Other substitutions

As suggested above, petroleum price increases have widespread effects throughout the economy, and there are still other areas where substitutions to reduce expenditures could be made. All travel is not work related, for example, and depending on preferences, some households may prefer to give up travel to the movies and vacation trips, for instance, rather than the traditional mode of travel to work. Savings can also be obtained by reductions in shopping trips, or by using bus or rapid transit for such non-work-related travel. Many of the substitutions involved, such as watching more TV rather than going to downtown movie theatres, may not be seen as significant sacrifices for consumers. Note also that additional savings will be generated for automobile owners who, either through choice or through legislated standards, purchase more efficient automobiles. Not only will there be savings on journeys to work, savings will also be realized on all other uses of the automobile. Given that the average consumer drives more miles in non-work-related activities than in commuting, these savings may be substantial.

A final type of substitution that will occur is between energy-related commodities such as travel and other goods. If price elasticities of demand for travel and other energy-using goods are low, much of the effect of petroleum price increases will be absorbed in reductions in other commodities. Substitution and complementary relationships among commodities will also be important in determining the final equilibrium consumption bundle. A family that decides to conserve on travel expenses by spending the summer vacation at the backyard pool rather than at a cottage by a lake may also spend less on boats, water skis, and fishing equipment.

There is no obvious direct effect of these types of substitutions on urban structure; the effects will be diverse and will depend to a great extent on the preferences of individual households. The overall indirect effect may be substantial, however, depending on the price elasticities involved. As one extreme case, if all energy-using activities have price elasticities of zero and if household real income is maintained in spite of the price increase in petroleum, then there will obviously be no effect on consumer demands for energy-related products, and thus no effect on the structure of urban areas. No one would seriously suggest that all such elasticities are zero, of course, and this example is provided simply to illustrate the crucial importance for the final outcome of parameters such as the elasticity of demand.

Finally, it must be remembered that petroleum price increases, because of the widespread use of petroleum products both for fuels and for intermediate inputs, will result in some price increases for all commodities. In a study prepared for the Ontario Economic Council, Melvin (1976), has made estimates of the commodity price increases that would be generated by a doubling of the price of crude oil, and some of these results are of interest for the present analysis. The study employed in input-output methodology to measure both the direct commodity price effect associated with a higher cost of petroleum products as input and the indirect effects associated with the fact that other intermediate inputs would also have higher prices because of higher oil prices. It was found that the average commodity price increase resulting from a 100 per cent increase in crude oil prices was less than 3 per cent, and that the range of individual commodity price changes was from 58 per cent for petroleum products to 1/2 of 1 per cent for communications. Excluding petroleum products, the price increases were typically quite small, with only chemicals showing an increase of over 5 per cent. The low average industry price changes somewhat understate the effects on consumers, however, since many of the industries showing the higher price changes have heavy weights in the consumer price index. For example, included among the top ten increases are the agriculture sector, some of the food processing sectors, and electrical appliances.

These relative price changes will affect the behaviour of urban residents in a number of ways. First, because the price changes for construction and for motor vehicle manufacturing are both well below the average, being 1.9 and 1.1, respectively, some substitution in consumption towards both housing and automobiles would be expected. Both changes would act to reduce density, since a move towards more housing units would be expected to imply a shift towards the suburbs, and relative price reductions for automobiles would reduce the total cost of commuting.

Another effect that is sometimes overlooked is the consequences for relative price changes of the overall increase in the consumer price index resulting from increases in crude oil prices. Suppose, for example, that a doubling of crude oil prices increases gasoline prices by 40 per cent and the consumer price index by 5 per cent. The relative price increase of gasoline in this case is $33\frac{1}{3}$ per cent. Some estimates of the effects of gasoline price increases on the demand for gasoline and travel seem to ignore this.

IMPLICATIONS FOR URBAN STRUCTURE

As was suggested earlier, the various effects described in the preceding section do not all have the same implications for urban structure. Changes in residential

location will be expected to increase the slope of the rent gradient and increase population density near the CBD. Industrial relocation, however, will tend to have the opposite effect, both because it will reduce the demand for downtown space and because it will reduce the incentives for workers to move towards the CBD. If the principal effect of petroleum price increases is to cause consumers to conserve on energy through shifting either to more efficient cars or to other modes of transportation, no specific effect on urban structure will be expected.[8] The direction of the effects of conservation of heating costs is unclear and the overall effect seems likely to be small. The principal implication of substitution away from other non-energy-related consumption goods would be to dampen the substitution effects for energy-using activities. It is clear, then, that no definite conclusions about the effects on urban structure are possible without a more careful theoretical and empirical examination of the models proposed above.

INTERURBAN EFFECTS

To this point the analysis has been concerned entirely with the question of how increases in the price of petroleum could affect the structure of a single urban area. There may also be interurban effects, however, which could have important secondary effects on individual urban areas. Thus if one urban area finds it easier to adjust to a change in petroleum prices so that rents and product prices are affected less, then there will be incentives for productive activity to move from one area to another. Such differences could result from the industrial makeup of the area, the industrial base, the preferences of households, or the transportation facilities. This section will examine these possible differences with a view to determining how important interurban effects are likely to be in determining the overall effects of petroleum price increases on the structure of urban areas.

Of course the principal category where differences between urban areas may be important is transportation costs. Differences here may occur for a variety of reasons. First, industries for which transportation costs are an important component of production costs will be disadvantaged relative to industries for which transport costs are relatively important. Such differences will depend on the nature of the product and the inputs, and whether markets are mainly local or

8 There will be important implications, however, for the urban community. Reductions in automobile trips will reduce pollution and congestion and reduce upkeep costs for roads and streets. Since emissions tend to be a function of the quantity of fuel burned, increasing automobile efficiency will also reduce pollution.

distant. In general, industries located in large urban areas would expect to be affected less than similar industries in a smaller urban centre, since more of the market would be local. In the Canadian context industries in remote areas and in the less densely populated provinces will generally be disadvantaged relative to industries in the Montreal-Toronto-Windsor corridor. One would expect a tendency for industry to become more concentrated when faced with higher transportation costs.

There may well be offsetting effects however. Industries that produce in central Canada and ship to the east and the west may find that the significantly higher transport costs would make the location of branch plants nearer these remote markets profitable. Whether this will be an important influence depends on the importance of transport costs in the overall cost structure and the relative costs of transporting inputs and outputs in the alternative locations.

In terms of their effects through interurban transportation, increases in petroleum prices are analogous to tariffs in international trade theory. Just as tariffs increase the cost to one country of importing a commodity from another, so gasoline price increases augment the costs for one urban area of 'importing' commodities. In the case of a gasoline price increase the 'tariff' is collected by the oil producers rather than the government, or in the case of Canadian-produced oil by governments through the oil companies. Some indication of how urban areas might be affected can therefore be obtained from tariff theory.

Assume an urban area that imports some commodities and exports others, and where some of both the imports and the exports are consumed. Further assume that the urban area does not, through its own purchases and supplies, affect the price of traded commodities. It is thus a perfect competitor in the markets for these goods. An increase in the price of gasoline will act like a tariff in that it will increase the cost of imports and reduce the relative return from exports. This would be expected to result in a production shift from the export good to the import type good and domestic goods that are not traded, and the specific effects on urban areas will depend on the type of goods imported and exported and where these industries are located. Suppose, for example, that the export industries tend to be located in the suburbs and that import-competing and domestic goods production is located in the CBD. These would be the locations expected to minimize transportation costs for both. With a decline in the export sector and a relative expansion of the import-competing and domestic sector, jobs would be created in the CBD and would disappear in the suburbs. Both would tend to increase the slope of the rent gradient and increase the population density near the CBD.

There will also be welfare effects for urban residents quite apart from those associated with location decisions. First, the transportation cost increase, acting

as a tariff, will make the average citizen worse off by reducing the quantity of goods and services he is able to consume. This is a simple consequence of the fact that more resources are now required for the transportation activity, which, by itself, does not provide utility. Second, since production has shifted, and given the fact that different productive activities can generally be assumed to use the factors of production in different proportions, there will be shifts in the demands for factors. This in turn will be expected to change relative factor rewards. Suppose, for example, that the export sector tends to be relatively capital intensive. The shift away from this sector would then be expected to increase the returns to labour and reduce the returns to capital.[9]

Other interurban effects may result from the differential effects that petroleum price increases may have on the production costs of different industries. As was pointed out earlier, because petroleum and petroleum products are so widely used in industrial processes, a petroleum price increase will have a pervasive price effect throughout the economy. But while all production processes will be made somewhat more expensive, some will be affected much more than others. There are two distinct ways in which petroleum is used in industry: as an intermediate product and as a fuel. In general, petroleum price increases in the former would be expected to increase product prices more than in the latter. First, for intermediate good use the petroleum input often forms an important cost item, such as in plastics, drugs, fertilizers, and gasoline.[10] Second, in such uses there seldom are close substitutes such as those possible when petroleum is used as a fuel.

The effects of petroleum price increases on urban structure through their effects on costs of production may therefore be quite significant, but it is difficult to arrive at any general assumption about how urban structure would be changed. Urban areas with a high concentration of petroleum-related industries would be expected to experience relative declines, but there seems to be no clear reason to expect the structure to be affected in any predictable fashion.

A final way in which interurban effects may be felt is through heating costs. In the United States there has been a good deal of discussion of the effect that increases in heating costs have on the relocation of industry. It has been argued, and some evidence has been provided, that the high cost of heating has resulted in an industrial shift to the 'sun belt,' mainly the south and southwest. It seems unlikely, however, that there would be much of this kind of effect in Canada.

9 That the wage-rental ratio will rise is clear. That real wages will rise and real returns to capital fall is a consequence of the Stolper-Samuelson theorem.

10 There are, of course, industries in which fuel inputs are also important, such as electricity, aluminum production, and various smelting processes.

First, the mean temperature differences in Canada are not nearly as large as they are in the United States. Second, the two relatively warm areas in Canada are the British Columbia coast and southern Ontario. Much of Canadian industry is already located in southern Ontario, and the transportation disadvantage of British Columbia will probably continue to outweigh a heating advantage. Finally, much of the industry not already located in a warmer area has a resource base that prevents relocation. This is particularly true of western agriculture, mining, fishing, petroleum extraction, and the forest sector. Of course higher heating and transportation costs will undoubtedly make it more difficult to develop viable industrial centres in the Maritimes and western Canada and thus may serve to slow down an industrial relocation that otherwise may have taken place.

In summary, while urban areas will be affected differently depending on their industrial base and location, there seem to be few general statements that can be made about the effect of petroleum price increases on interurban equilibrium. Even more difficult are conclusions about how the internal structure of such urban areas would be affected.

4
Existing theoretical models

INTRODUCTION

This chapter will provide a brief review of some of the models found in the urban economics literature that address the theoretical issues outlined in Chapter 3. The principal model of residential location was developed by Muth (1969), and his analysis will be summarized. An extension of this analysis specifically to include energy price increases developed by Romanos (1978) will also be considered. Several models to explain the locations of firms and households have been developed by Mills (1972) and extended to include increasing energy prices by Albert and Banton (1978) and Waymire and Waymire (1980). Simple versions of these models will also be reviewed.

There are also several earlier models of historical interest, including those of Wingo (1961), Niedercorn and Kain (1963), Alonso (1964), Lowry (1964), and Forrester (1969). An excellent survey of these is included in Mills (1972, Chapter 4). There have also been numerous extensions and elaborations of the Mills and Muth models. Some of the most relevant for the present analysis would include Albert (1978), Robson and Scheffman (1978, 1979), Miyao (1975), Small (1981), and Wheaton (1974).

MODELS OF RESIDENTIAL LOCATION

Although the relationship between travel costs and urban structure has long been studied, modern economic analysis of the subject was given its main impetus by the seminal contribution by Muth (1969). Muth developed a formal model that explained how residential land values and residential densities would be determined. Although the Muth model and its successors are simplistic, they

do shed considerable light on the relationship between travel costs and urban structure.

This section begins by explaining in simple terms the workings of these models. Later in this study these simple models will be expanded in various ways to attempt to capture more of the 'reality' of how travel costs could be expected to affect urban structure. Imagine an urban area with N identical consumers (identical with respect to preferences and income). Suppose this city is located on a featureless plain, so that special topographic features that might affect consumer preferences for location are absent. In this simple city all production is assumed to occur in a central area called the central business district (CBD). All consumers in this city reside outside the CBD but must commute to the CBD every working day. Denote by u the commuting distance to the CBD and let $t(u)$ be the annual commuting travel costs from distance u.

Initially the analysis abstracts from structures and assumes that a consumer's dwelling consists only of land. Suppose that for some reason (e.g., zoning) all residential lots are of the same size, and denote the size of a residential lot by q. Assume further that all consumers rent their accommodations on a yearly basis. The way in which travel costs ($t(u)$) affect rents is now examined. Consider a commuter living at distance u and another commuter living at distance v from the CBD. Denote the rent per unit of land on a lot of size q at distance u by $r(u)$. Recall that by assumption all consumers are identical. Therefore rents in the city must adjust so that in equilibrium all consumers are equally well-off (otherwise if consumer A located at u was better off than consumer B located at v, consumer B would bid up the rent on A's lot).

Let y be an (identical) consumer's annual income. Then $y-t(u)$ is the income net of travel costs for a consumer located at u, and $y-t(u)-r(u)q$ is the amount such a consumer has to spend on goods other than land. Since all consumers live on lots of identical size, for rents to be in equilibrium the amount of income left to be spent on goods other than land must be the same for all consumers; that is,

$$y-t(u)-r(u)q=y-t(v)-r(v)q \tag{1}$$

for every location u, v. (Otherwise consumers cannot be equally well-off.) From equation (1) the relationship between rents and location can easily be derived:

$$r(u)-r(v)=[t(v)-t(u)]/q. \tag{2}$$

Thus, the difference in rents is the difference in transportation costs. Therefore, if, as one would expect, travel costs increase with (commuting) distance from the CBD, rents will decline with distance from the CBD. Equation (2) also shows that if travel costs increase (because, for example, of an increase in gasoline prices) to $kt(u)$ $(k>1)$, rents would fall faster with distance from the CBD.

Thus far the analysis has highlighted the relationship between residential rents (values) and travel costs. Since, by assumption, lot sizes were fixed, travel costs have no effect on urban structure. The effect of allowing market forces to determine lot sizes is now considered. Assume that in the initial situation lot sizes are determined completely endogenously. Consider again (identical) consumers residing at distances u and v, respectively. If $t(v) > t(u)$, the consumer residing at distance v has less income net of commuting costs. This requires that rent (per unit of land) at distance v must be less than rent at distance u; otherwise the consumer at v would be worse off than the consumer at u. For example, it can be shown that if u and v are close to one another, equation (2) must hold.[1]

Now consider lot size at u and v. To examine what happens to lot sizes with distance, it will be assumed for simplicity that there is a single non-land good which consumers purchase and that its price is unity. Figure 1 represents the preferences of one of the identical consumers residing at u. As before, denote by q the size of lot and let x denote the amount of consumption of the other good. The curve I represents the combinations of q and x which leave the consumer equally well-off. The line AB is the budget line which traces out the combinations of q and x which the consumer can afford to purchase if the rent per unit of land at u is $r(u)$. Thus if the consumer spends all his income x, he can purchase $y - t(u)$ units. If he spends all his income on land, he can rent $[y-t(u)]/r(u)$ units.

As shown in figure 1, if $r(u)$ is the rent, a consumer at u will rent a lot of size $q^*(u)$ and purchase $x^*(u)$ of other goods. Now an identical consumer locating at v (for $t(v) > t(u)$) must, in equilibrium, be as well-off as the consumer at u, so that he too must be able to attain a consumption bundle somewhere on I. Since his net income ($y - t(v)$) is smaller and the rent per unit of land at v is smaller than at u, the consumer at v will have a budget line that is flatter than AB. Since the consumer at v must be able to achieve a consumption bundle on I (but no higher), it is easily seen that $r(v)$ must be low enough so that the budget line with intercepts $y - t(v)$ and $[y - t(v)] / r(v)$ just touches I. The reader can easily see that for such a budget line the consumer at v will purchase a smaller quantity of x and *rent a larger lot*. Therefore lot sizes will increase with distance from the CBD or, alternatively, residential density will decrease with distance. Figures 2a and 2b depict how rents, $r(u)$, and residential density (dwellings per unit of land), $d(u)$, would be expected to vary with u.

The steepness of these two gradients is related to the travel cost function in the following way. Returning to equation (2), it can be shown that equation (2) holds

1 It is easily shown that $dr(u) / du = -t'(u) / q(u)$.

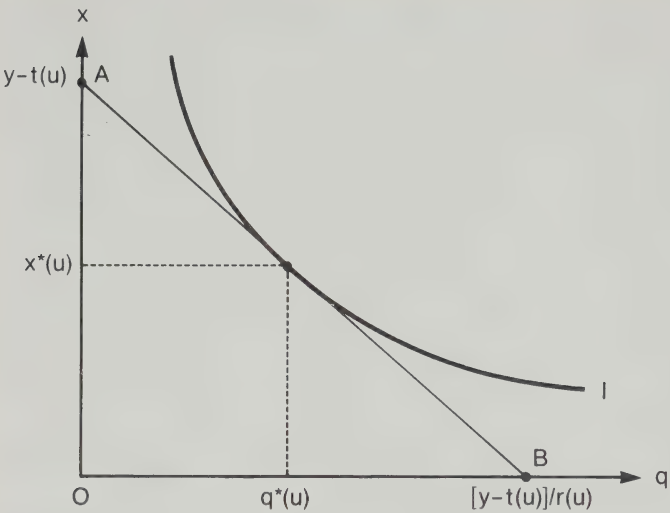


Figure 1

approximately even if density is variable, if u is close to v and q is interpreted as $q(u)$. We can rewrite (2) (approximately) as

$$[r(u)-r(v)]/(u-v)=-[t(u)-t(v)]/(u-v)q(u). \tag{3}$$

Now for u close to v, $[r(u)-r(v)]/(u-v)$ is approximately the slope of the rent gradient at distance u, and $[t(u)-t(v)]/(u-v)$ is approximately the slope of the travel cost function at u. Therefore we see that the slope of the rent gradient is directly related to *marginal* transportation costs.

Now consider an experiment where, in the simple city, higher travel costs are assumed. Higher transportation costs have two effects. They lower income net of travel costs at each distance, thus reducing lot size and increasing density, other things being equal. From (3) it can be seen that this would tend to make the rent gradient steeper (since $q(u)$ falls). If, in addition, marginal travel costs increase (if increased travel costs are the result of increased gasoline costs), there is a further steepening effect of the rent gradient. Therefore, an increase in travel costs (which does not result in lower marginal travel costs) would tend to steepen the rent gradient and density gradient depicted in Figures 2a and 2b. In particular, the city with higher travel costs would be smaller (because densities are higher for a given population). Chapter 6 will consider several simulations which illustrate how travel costs would affect rent and density gradients and city size in simple models with realistic parameters.

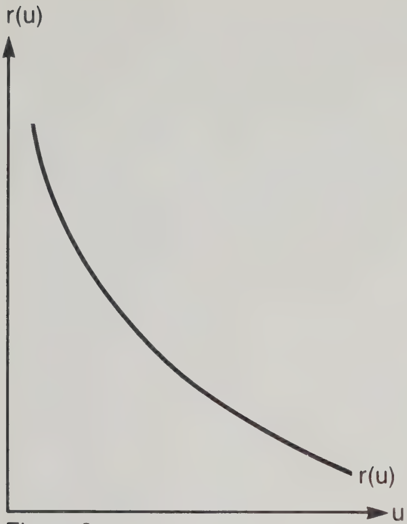


Figure 2a

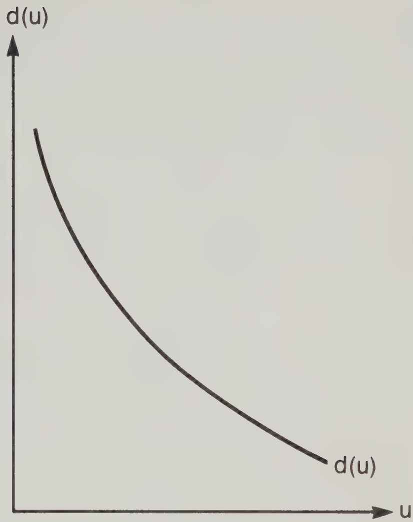


Figure 2b

If consumers are visualized as commuting to the CBD by automobile, we see that, being smaller, the city with higher travel costs (but other things equal) will have less total miles travelled in aggregate for commuting purposes. (Recall that by assumption each consumer makes one round trip to the CBD per working day). This urban structure will tend to adjust to increases in travel costs in such a way as to economize on travel.

The equilibrium for the model described above can be illustrated by use of a simple diagram. Consider a representative household concerned with the question of where within the city it should locate. By the use of equation (3) it was shown that at the equilibrium location a household would equate the extra savings in housing expenditure associated with moving one distance unit further from the CBD with the extra travel cost associated with such a move. In Figure 3, where distance is measured horizontally and cost vertically, T represents the marginal travel cost function and Q the marginal savings function associated with falling rents as one moves further from the CBD. The T curve is downward sloping because of the assumption that, while travel costs increase with distance, they increase at a decreasing rate.[2] The Q function is downward sloping because of the assumption that rents decline as one moves further from the CBD. Note

2 One could assume that travel costs are a linear function of distance, and the analysis would be unaffected. In this case T would be horizontal.

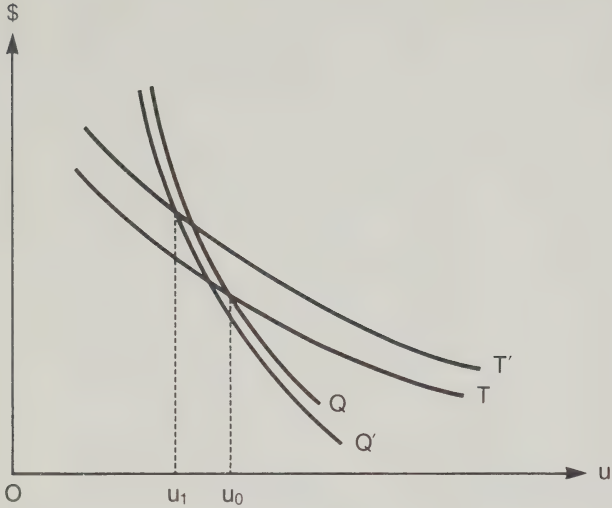


Figure 3

that T must intersect Q from below; otherwise it would always be profitable to move further away from the city centre, and in such a situation a city would not exist. In the situation shown the household would locate at distance u_0 from the CBD, or more generally at distance u_0 from the employment centre.

Figure 3 can be used to show the effects of an increase in gasoline prices. First, the marginal cost of travel will increase, shifting T to T'. The increase in travel costs will also increase the slope of the rent gradient and reduce the quantity of housing demanded at each u, therefore shifting the Q curve as well.[3] A new equilibrium will be at a point such as u_1 to the left of u_0.[4]

In a recent paper Romanos (1978) has extended the Muth analysis with the specific purpose of including the effects of energy price increases on urban structure and form. Romanos argues that the price of housing can be viewed as the sum of two terms, so that

$$r'(u) = r^1(u) + r^2(u). \tag{4}$$

Here $r^2(u)$ is the component of the price of housing services attributable to energy costs, and $r^1(u)$ includes all other costs. It is then argued that while $r^1(u)$

3 The Q curve is the product of the quantity of housing units demanded and the slope of the rent gradient, and an increase in the price of gasoline will move them in opposite directions. Thus Q could shift up or down.

4 It can be shown rigorously that the shift in Q can never completely offset the shift in T. Thus the equilibrium location must move to the left when marginal travel costs rise.

decreases with distance, for the same reasons as described above, $r^2(u)$ would be expected to increase with distance 'owing to the association of longer distances with lower densities and higher energy consumptions' (Romanos, 1978, 100). This argument seems to be based on his earlier observation that suburban families use more energy than urban ones, and that single-family houses use more energy than apartments (ibid., 97).

Romanos then argues that transportation costs can also be written as two terms, the second of which is cost of fuel and the first all other costs. Thus $t(u)$ is replaced with

$$t'(u) = t^1(u) + t^2(u). \tag{5}$$

Then, in terms of figure 3, an increase in the price of gasoline will result in the new curves T' and Q'. The new equilibrium location, u_2, is closer to the employment centre because of the shifts in both T and Q.[5]

There are a number of points on which Romanos's arguments are less than completely satisfactory. He argues that the slope of the housing-saving function will be less than it was before the energy price increase. This argument depends, however, on the somewhat tenuous proposition that heating costs rise as one moves away from the CBD. It certainly is reasonable to assume that heating costs per dwelling rise with distance from the CBD, but the term $r^2(u)$ is heating cost per unit of living space. The suggestion that the heating expense per unit of space will rise with distance from the CBD is anything but obvious. Indeed it was argued in Chapter 3 that because of the age profile of housing, the difficulty in insulating older homes, and the relative efficiency of building new, energy-efficient dwellings as opposed to converting old ones, heating costs per unit of space may fall with distance from the city centre. If this is the case, Q will shift up with an increase in energy prices and we could have the situation of Figure 4. In the situation shown the two shifts are exactly offsetting, resulting in an unchanged residential location. Obviously such a special case would occur purely by chance, but there would seem to be no a priori reason to suppose that Q could not shift by as much as T. Indeed, given the fact that a much larger proportion of household income is spent on heating than is spent on the average commuting trip, and if there is a substantial difference in the heating efficiency of dwellings, as casual observation would suggest, there may be a presumption that the shift in Q will be the larger, leading to the conclusion that an increase in petroleum prices will result in an increase in the equilibrium distance from the CBD with a consequent reduction in density.

There is one other rather curious feature of Romanos's model. After presenting the argument of Figure 3 to show that households will move towards their

5 Romanos does not consider the shift in Q associated with the increase in travel costs.

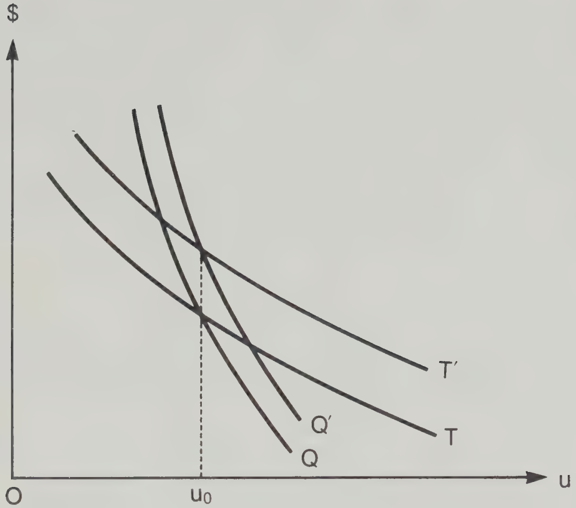


Figure 4

employment centres, he argues that these employment centres will typically be located in the suburbs. He then suggests that future development will result in increases in density around these suburban employment centres rather than around the CBD. This argument would seem to be at variance, however, with his reason for assuming that heating costs are an increasing function of distance, namely that suburban households use more energy than urban households do. This clearly seems to be an argument relative to the CBD, not to suburban employment centres.

The extension of Muth's model to include energy costs has not resulted in unambiguous predictions about the effect on urban structure and density. The tendency of higher transportation costs to encourage households to move closer to the CBD (or employment centre) may be either reinforced or offset by the effect of heating costs on residential location. This in turn will depend on how the unit heating costs vary with distance from the CBD. The question of how heating costs will affect residential location will become relatively more important when models that allow substitution in the transportation sector are developed. Such substitution will significantly reduce the shifts in T of Figures 3 and 4, leaving heating costs the principal determinant of changes in u.

The model described above is very simple. However, it does provide some important insights into how travel costs, urban structure, and residential rents (values) are related. Several implications of allowing more 'reality' in the model are now examined. First consider the effect of explicitly introducing structures

(i.e., housing) into the model. This can easily be done by assuming that housing services can be produced using land and 'capital' described by a production function $h(k, q)$, where k is the amount of capital, q is the lot size, and $h(k, q)$ denotes the quantity of housing services produced using inputs k and q. If capital services can be rented at price P_k, then a competitive housing industry would rent capital services and land to produce housing that it would rent to consumers.

For the reasons explained above, land located further (in commuting distance) from the CBD would (other things being equal) command a lower rent; thus housing would be expected to be more land intensive further from the CBD (since land is relatively cheaper there). This expectation, of course, is consistent with the stylized facts of most urban areas in which the amount of land used for dwelling units generally increases with distance from the CBD, while the 'amount' of structure per dwelling unit decreases (e.g., moving from apartments near the CBD to single-family, detached housing on large lots in the distant suburbs).

Therefore bringing structures into the model does not change the basic insights gleaned from the simple model about the relationship between urban structure and travel costs. However, recognition that housing does require structures that are generally quite long-lived does remind one that urban structure, once in place, is not likely to be very adjustable to changes such as increases in travel costs (gasoline prices). This has important implications that will be addressed below.[6]

One obvious objection to the simple model is that no modern cities have all employment concentrated in the CBD. In fact, there has been a trend to the suburbanization of employment, so that CBD-oriented employment now accounts for only about 50 per cent of employment in the 'typical' city. Despite this trend, the CBD is still a critical locational factor in the relationship between urban structure and travel costs. For example, we shall see in Chapter 8 that the CBD is an important area of employment for residents of the Toronto area, independent of their place of residence.

How does the recognition of the importance of non-CBD employment modify the conclusions of the simple model? Later in this chapter models will be discussed in which both employment location and residential location are endogenous. Therefore attention here is confined to a few general points. First, it should be clear that the closer a suburban residential area is to large suburban employment centres, the more valuable residential land will be and the larger the associated residential densities will be (other things being equal). Thus the

6 For a rigorous model that incorporates structures see Henderson (1977) and the literature cited there.

suburbanization of employment would be expected to weaken the relationship between commuting costs *to the CBD* and urban structure. None the less, since the CBD is generally an important source of employment for suburban communities, this relationship, although weakened, would be expected to hold (other things being equal).

Another important factor to consider is that commuting is only one component of a consumer's required urban travel. Trips to shopping areas, social activities, and so on are also important components of travel, and therefore of travel costs. Thus closeness to these other types of travel destinations would be expected, other things being equal, to make residential land more valuable and lead to larger densities. In summary, one would expect that higher travel costs would lead to a more compact configuration of place of residence, place of employment, and other important travel destinations. This might occur through a higher concentration of employment in a CBD-type area with consumers more closely clustered around the CBD, or through a formation of increasingly independent suburban employment centres with consumers clustered around them. These possibilities will be considered further below.

The simple model outlined above assumes that consumers are identical. This allows a simple explanation of the relationship between travel costs and urban structure. However, it should be clear that this assumption is not essential to the basic points made. Other things being equal, locations with higher travel costs are going to be valued less, and consumers locating there will tend to choose lower density residences than they would at locations with higher values and lower transportation costs. Notice that 'other things being equal' is an important restriction here. Neighbourhood and topographic factors can have a major impact on property values and densities. None the less, travel costs would be expected to have an impact on values and densities, and in particular, increases in travel costs would be predicted to have an effect on urban structure.

Now consider the determinants of travel costs. In the simple model travel costs were taken to be given as some function $t(u)$. In order, for example, to predict the expected effects of increases in the price of gasoline, we must describe how increases in the price of gasoline affect travel costs. First consider travel by private automobile. Direct travel costs include both gasoline costs and the other costs of operating a vehicle. These other costs include depreciation, maintenance, etc., to the extent that they can be ascribed to the mileage related to commuting (in the simple model where commuting is the only form of travel). For example, a consumer located ten miles from his place of employment will bear higher non-gasoline automobile costs of commuting than a consumer located one mile from his place of employment.

Recognition that non-gasoline travel costs are an important component of travel costs reminds us that increases in gasoline costs will not generally result in

a proportional increase in travel costs. Furthermore, the effect of increases of gasoline costs on travel costs is to some extent endogenous for two reasons: first, a consumer can substitute towards a less gasoline-intensive (higher mpg) car; and second, mpg aside, the consumer can substitute towards automobiles with lower non-gasoline travel costs. Since we shall be addressing consumer substitution possibilities in detail in the next chapter, this discussion is concluded with a cautionary note that the relationship between changes in gasoline costs and changes in travel costs is not likely to be one-to-one.

Besides the direct costs of travel, there are important indirect costs such as time costs. Travel uses time that could be used for other purposes (work or leisure). It is quite straightforward to do simple calculations to obtain an idea of the relative importance of time costs. A reasonable 'ballpark' figure for the direct costs per mile for an automobile trip would be $0.20. Now consider the fact that such a trip might have to be made at an average speed of 20 mph. Then one mile takes three minutes, and if leisure time is valued at $3.00 per hour, the time costs per mile would be $0.15. (In Chapter 8 we shall discuss empirical estimates of the value of travel time and the amount of time spent per commuting trip.) Even this simple calculation should make it clear that the time cost of travel is an important component of total travel costs. Residential areas near high speed (low time) commuter networks such as subways and high speed commuter highways would be expected to have higher value and density, other things being equal, and this prediction is borne out by simple observation and thorough research of modern cities (see, for example, Davies, 1975).

Recognition that the time costs of travel are an important component of total travel costs has important implications. Some of the implications are similar in nature to those outlined above in the discussion of the importance of non-gasoline direct travel costs – that is, gasoline costs are only one component of travel costs, and if gasoline prices rise, it will generally be possible to economize on total travel costs by substituting to reduce non-gasoline travel costs. One obvious example of the possibility of such substitution is if increases in gasoline prices cause the costs of automobile travel to rise faster than public transportation costs, a consumer may decide to use public transit (which in many instances may be a more time-intensive mode of travel) instead of a private automobile. Car pooling and walking are other obvious methods of substitution. Since the evidence on modal choice is discussed in Chapter 7, this issue need not be discussed further here.

Another implication of the importance of time costs is that public decisions regarding road networks and other travel systems can have profound implications for urban structure. Larger, more efficient systems of commuter highways, subways, and GO-trains increase the incentives for suburban development and can have a significant effect on the amount of gasoline used in urban travel. This

point will be considered later in this study when the policy issues arising from an increase in gasoline prices are summarized.

The last point to be made about simple residential location models in this chapter is that at any one time the existing structure will predominate in the faces of 'reasonable' changes in factors such as travel costs. Thus although real travel costs have increased in the post-OPEC world, massive demolition and rebuilding of existing urban structure has not been observed nor would it be expected. This is not to say that such demolition and rebuilding is impossible; rather that travel costs have not increased to a level sufficient to justify such a change in existing structure. In Chapter 6 a simple model is developed, which explicitly recognizes that the existing structure will predominate in the medium run and explores two important implications of that model. First, the fact that the existing structure cannot be changed very easily makes new development more sensitive to changes in basic parameters such as travel costs. Second, the slowness of the existing structure to adjust may require some adjustment in the value of existing residential real estate in a manner that may depend on its location.

MODELS OF INDUSTRIAL LOCATION

In this section several models that have been developed to explain the location of industry will be reviewed. Two kinds of models are considered. First we look at models that deal exclusively with the location of industry, of which the paper by Moses (1962) is a good example. This paper is discussed and an extension by Waymire and Waymire (1980) is surveyed. A second branch of the literature combines household location and industrial location and can thus be seen as an attempt to combine and co-ordinate the models of Muth and Moses. The principal reference in this area is Mills (1972), in which three general equilibrium models of the urban economy are presented. Mills's discussion begins with the simplest model, which captures some of the important elements of urban structure, and the other two models are extensions to consider congestion and the introduction of an efficient transportation system. Only the first of these three models is considered here. As will be seen, even for the simplest model the analysis becomes complex, and an arrival at any conclusions requires simplifying assumptions that are so unrealistic as to make the models less than persuasive. Extensions of the Mills analysis by Albert and Banton (1978) and Waymire and Waymire (1980) are also reviewed.

The Moses model is an attempt to place the theory of the firm in a spatial setting. It is assumed that two inputs are employed to produce a single output. The sources for the two inputs and the market for the output are spatially separated and the distances between them are known. It is assumed that the firm

must pay the base price plus the transport cost (assumed to be a linear function of distance) for the two inputs and must also pay the cost of transporting the output to the market.

Not too surprisingly it is found that the optimal location for the firm will depend on all of the variables in the model, including the nature of the production function, the cost of transportation for both inputs and outputs, prices of inputs and outputs, and the location of the market for output. Furthermore it is shown that if there are any increasing returns to scale in the production process the optimal location will also depend on the level of output. Indeed, with increasing returns one would expect a different optimal location for every output level.

While useful in identifying the variables that will be important in determining the optimal location of an industry or firm, the Moses model does not shed much light on how a gasoline price increase would be expected to influence the location of firms within an urban area and thereby influence urban structure and density. In the first place, as Moses himself admits, the model is a partial equilibrium consideration of a single firm and does not consider the interaction among a number of firms. Furthermore, while the factors which affect optimal location are identified, no specific rules are derived that would allow general statements about movements of firms in the face of transportation cost increases. Finally, no specific attempt was made to relate increases in gasoline prices to the relative transportation costs for the various inputs and outputs, as would be required for a complete understanding of the interactions among gasoline price, transportation costs, and the optimal location of firms.

A paper by Waymire and Waymire (1980) does attempt to investigate the effect of rising energy prices on urban space. They chose as their starting point a model that emphasizes the question of optimal plant location in an urban area, an approach which has its origins in the paper by Moses (1962). The particular approach used follows that of Miller and Jensen (1978), in which a single output is produced using land, capital, labour, raw materials, information, and energy as inputs. Transportation costs for output, labour, raw materials, and information are all considered to be functions of the level of output, distance from the CBD, and energy. The prices facing the firm are defined as the sum of market prices plus a transportation cost component (where relevant),[7] and the firm is then assumed to maximize profits subject to these various constraints. Solving this maximization problem, Waymire and Waymire derive a complex expression for the change in the price of land with respect to a change in distance from the CBD.

7 Transportation costs are assumed zero for land and capital.

The conclusions reached are that on balance the effect of increases in energy costs will result in a tendency towards a higher concentration of firms in the central city. They see as the central reason for this the fact that information costs increase with distance from the CBD. They argue that higher costs of transporting output to the CBD and higher information costs offset the influence of the cost of transporting labour and raw materials. They conclude that 'information costs tend to keep the centralized distribution as the most efficient one. The model indicates that information costs tend to offset the impact of energy prices on the transportation costs of labour and material inputs' (420).

The Waymire-Waymire analysis can be criticized on a number of grounds. First, it is very difficult to see how their conclusions arise from their algebra, since the expression for the change in the price of land clearly does not have an unambiguous sign. No specific conditions are derived to show what relationships among the parameters would give rise to these conclusions. They argue that the expressions for information costs and product transportation costs could outweigh those of intermediate inputs and commuting costs, but there is no indication of what parameter values would be required for such a result. Perhaps more crucially, they depend on the costs of information increasing with rising energy prices to give them their result. As was argued earlier, the assumptions that there will be significant information cost increases associated with moves to the suburbs and that energy costs are an important determinant of the level of information costs both seem to be very tenuous points. Thus the authors' conclusion that with increases in energy costs 'information costs tend to keep the centralized distribution as the most efficient one' (420) is very difficult to accept on the basis of the evidence provided. Indeed, given the complexity of the relevant partial derivative and the uncertainty surrounding the sign of many of the terms in their expression, it is difficult to escape the conclusion that the authors are simply trying to muster support for a preconceived position.

The models of industrial location so far reviewed have not been very useful in providing any general results on how the structure of an urban area would be affected by an increase in gasoline prices. One reason is that in the models attention has been confined to the production sector, with no discussion of the interaction between producers and households. There are models that have attempted to examine the joint problem of household and firm location, the seminal work in the area being that of Mills (1972). Because this analysis attempts to combine two problems, each of which has already been seen to be difficult, it comes as no surprise to find that even the simplest formulations are quite complicated.

While the Mills model does not explicitly consider the question of how gasoline price increases can be incorporated, this question has recently been

taken up by Albert and Banton (1978) and has been reviewed by Waymire and Waymire (1980). These models are now considered.

As has been suggested, even the simplest model of industrial location becomes quite complex and difficult to summarize. We shall present a brief summary of the Mills model and outline the conclusions. A somewhat more technical version is presented in Appendix A. Mills assumes two goods: X_1 is an export good shipped from the CBD and X_2 is housing services. A simple fixed coefficient production technology is assumed with land the single input. The constants a_1 and a_2 represent output per unit of land for X_1 and X_2 respectively. Further assumptions are included to ensure that all labour is employed, and a condition is derived that gives the size of the urban area in terms of the coefficients a_1 and a_2 and the total output of the two commodities.

Having constructed the basic model, Mills then defines two allocations of firms and households. In the segregated allocation the export industry is located immediately around the CBD (the export facility) while all households are located in a doughnut-shaped area around the land used to produce X_1. The alternative is called the integrated allocation, and here both the production of the export good and households are distributed evenly throughout the urban area. Thus at every point in the urban area there exists both a producer of X_1 and a household.

It is clear that the segregated allocation minimizes the cost of transporting the export commodity, while the integrated allocation minimizes the cost of transporting workers to their place of employment. If t_1 and t_2 are the cost per mile of transporting X_1 and workers respectively, Mills shows that the integrated solution is optimal if $(t_1 - t_2) / t_2 > a_2 / a_1$. If this inequality is reversed, the segregated solution is optimal. Details of this derivation are shown in Appendix A.

As Mills himself points out this is a very simple model, which does not include many of the variables that one would expect to find in a model designed to explain industrial location in an urban area. The model is linear, which implies both constant returns to scale and no substitution in production. Increasing returns to scale are generally seen as a central feature in the explanation of industrial location, and the substitution of capital for land as rents increase towards the CBD is a feature of most urban areas. The simple model also ignores all the externalities or agglomeration economies and diseconomies that are generally assumed to exist in urban areas. Missing are both the externalities associated with information and the diseconomies of having households next to factories.

While the model is simple and may be even less general than Mills has claimed, it is nevertheless quite suggestive for the issue at hand. Although there will be many forces acting to determine the location of industry and households, it does seem clear that in general the relative costs of transporting factors of

production and output will be among the important determinants of the location of economic activity. Increases in petroleum prices will change these transportation costs, and the more important the costs of transport for output are relative to factor transport costs, the stronger the tendency for higher petroleum prices to lead to a flattening of the density gradient for an urban area will be. All of this, of course, presumes that the export good must be transported to the CBD. As was suggested in Chapter 3, if transport of the final product is by truck, there must be a presumption that higher gasoline prices will result in shifts of industry to the suburbs, with a tendency of households to locate around these new suburban employment centres.

Mills also examined the circumstances under which competitive markets would achieve the optimal allocation of households and industry. Mills concludes that the market will give rise to the optimal distribution, but it is of interest to note that this result depends crucially on the fact that the wage rate paid at each distance u appropriately reflects the cost to the worker of commuting to that location. If workers are not paid in relation to their place of employment, there is no incentive for industry to locate according to the integrated allocation, even when it is optimal to do so. This fact reinforces the conclusion reached in Chapter 3 regarding the importance for efficiency of eliminating institutional rigidities on wage rates in urban areas.

A variant of the Mills model has been employed by Albert and Banton (1978) to analyse the effect of energy price increases on urban structure. The major differences from Mills's model are that the two goods assumed to be produced are housing and services rather than housing and an export good, and the inclusion of information as an input to the production function for services. The argument for using services as the other produced good is that the service sector is the single most important industry in a major urban area, and a sector that is crucial to the well-being of the central city. It is argued that the principal reason for the location of the service sector in the CBD was the importance of information, an input that is assumed to have significant agglomeration economies.

The Albert-Banton analysis leads to an inequality similar to (7), except that the transportation cost t_1 is replaced by the cost of information. The cost of information is assumed independent of energy prices, and thus as energy prices rise, there is a presumption that the conditions for an integrated allocation of the service industry and the household sector will prevail. Thus energy price increases will promote the suburbanization of the service sector. Other arguments could also be formulated to support this conclusion. One impediment to the integration of the manufacturing sector and the housing sector is the pollution externalities associated with many manufacturing industries. The service

sector is virtually pollution free and thus this impediment disappears. Furthermore, there are fundamental differences between the transportation cost variable of manufacturing and the information costs associated with the service sector. A manufacturing firm that relies on the CBD as an export point cannot avoid the transportation costs associated with delivering its output to the CBD. The information costs of the service sector are generally not related to the CBD per se but are associated with the agglomeration economies associated with the similarity of firms. These agglomeration economies could be achieved in the suburbs as well as in the central city. While at an earlier time in the development of urban areas it was doubtless true that efficient information centres were at the ports of entry where mail, etc., were delivered, the advances in communications systems and computer technology now allow businesses almost instant access to a tremendous range of information at almost any point in an urban area.

Waymire and Waymire (1980) have also discussed the effects of rising energy prices on urban structure. They review the analyses of Mills, Muth, Romanos, and Albert and Banton and in particular are critical of Albert and Banton's assumption that information costs are independent of energy costs. They go further and argue that, with respect to rising energy prices, 'there is no evidence to suggest that the rate of change in transportation cost for commuters is faster than the rate of change in information costs' (412). Waymire and Waymire are therefore not persuaded that even for the service sector an increase in the price of energy will result in a shift of firms to the suburbs.

The review of the literature undertaken in this section emphasizes the difficulties encountered in attempting to reach definite conclusions about the effect of gasoline price increases on industrial location and urban density. Even the simple bare-bones models of the type described by Mills do not seem to yield unambiguous predictions, and these models are too simplistic to provide anything but a hint of what might be expected when some of the important but analytically difficult complications are introduced. The basic problem would seem to stem from the fact that properties traditionally used to explain the existence and structure of urban areas – such as economies of scale and externalities – are among the least well understood and most difficult topics in economics. When these are combined with an already complex model, the urban economist is faced with a formidable task indeed.

It is worth stressing, however, that the difficulty is not that one is unable to determine how an individual firm will respond to an increase in the price of gasoline. Given specific information about a firm's production function, sources and costs of inputs, transportation needs, market locations, and demand conditions for the product, no particular difficulty would be encountered in determin-

ing how the firm would respond to a gasoline price increase. Nor would it be particularly difficult to formulate a set of criteria to classify firms as to their expected response to petroleum price increases. For example, consider a firm located near the CBD that receives all material inputs by truck from distant sources and ships the final product to other urban areas, and for which labour is at least as plentiful in the suburbs as it is near the CBD. One can predict that for such a firm price increases of gasoline, by making transportation costs a more important cost item, would produce a strong incentive to relocate in the suburbs (or perhaps even in another urban area closer to inputs or product markets).

Alternatively, consider a firm that supplies a service to consumers located near the CBD in a specific urban area, and for which transportation costs are a small component of overall operating costs. For such a firm it is easy to predict that even major increases in gasoline prices are unlikely to result in a relocation to the suburbs. One could classify firms according to factors such as importance of transportation and location of inputs and markets, and firms could thus be grouped according to the likelihood of relocation in the face of gasoline price increases.

But while such a taxonomy would be possible (although very time consuming), it would still not provide any general conclusions as to how 'the firm' would behave in the face of transportation cost increases, and this is the basic difficulty. Because of the differences among firms and because of the differences in the distribution of these different firms among urban areas, it becomes difficult (or impossible) to formulate any general conclusions that would apply to the 'typical' urban areas. Thus the theoretical models that have been reviewed above provide only very limited insights into real-world problems of industrial location.

Of course some conclusions are possible. Given the predominance of truck transport and unless one believes that there will be a resurgence of the railways (which seems unlikely), it seems clear that there will be some tendency for higher gasoline prices to cause a relocation of industry towards the suburbs. In other words, it is easy to describe firms that will find it profitable to move to the suburbs if gasoline prices rise; it is much more difficult (but not impossible) to envisage firms that will move from the suburbs to the CBD. However, sophisticated theoretical models are not required to arrive at this conclusion.

5

Substitution responses to gasoline price increases

INTRODUCTION

Chapter 4 described the simple models of urban structure associated with the work of Mills, Muth, and Moses. Several extensions of these models designed explicitly to analyse the effects of energy price increases on urban structure were also reviewed. All these models have one important feature in common; they suppose that the relationship between travel and transportation costs and distance travelled is fixed, so that the only method of reducing such costs is by reducing the number of miles travelled. In practice there are a number of ways in which economic units could reduce per unit travel costs. From the point of view of the production of travel services some substitution will be possible. One can view travel services (that is, carrying a given load a given distance) as being produced by some function of capital, labour, and energy (for example, gasoline). If some substitution exists among these inputs, with an increase in gasoline prices firms and individuals would be expected to substitute away from this higher priced input and to use more labour- and capital-intensive travel methods. In the next section this kind of substitution for firms is considered.

For consumers, while some substitution on the production side may be possible, the more important kinds of substitution will take place on the demand side. As suggested earlier, when faced with higher gasoline prices consumers may choose to spend less on gasoline through a switch to smaller cars or change their mode of travel rather than reduce the distance travelled. Note that such a switch must result from the consumer's reassessment of the value of services provided by the automobile, implying that such services are an argument in his utility function. This possibility simply does not exist in the models so far described. Even those models specifically designed to investigate the effects of energy price increases on households, such as the Romanos (1978) paper, do not allow for the

possibility of substitution by consumers. The formulation of the consumer maximization problem in the urban economics literature simply does not permit this type of substitution. This argument, however, should not be interpreted as suggesting that the urban location models of Muth or Mills are in any sense incorrect. These models were not specifically designed to analyse the effects of energy price increases, and thus they clearly cannot be criticized for their failure to do so adequately. It would seem appropriate, however, that models designed to investigate the consumers' response to higher energy prices allow for the consideration of substitution effects that the empirical evidence suggests are of considerable significance.

Two types of consumer substitution are considered. First, an individual, when faced with a higher price for gasoline, may decide to conserve by switching to a more energy-efficient automobile. Such a shift would reflect the fact that while the services of a large automobile provide utility to the consumer, the extra services provided by a large car are seen to be dispensable as the price of these services rises. The analysis of this situation obviously requires that the services of automobiles be included as an argument in the utility function. Second, an individual may react to higher gasoline prices by switching to a completely different travel mode, a bus or the rapid transit system, for example. While such modal shifts may also reflect some reduction in the demand for the services provided by an automobile, they also reflect a re-evaluation of the importance of travel time. This formulation requires that time, or leisure, be included as an argument in the utility function. These two types of substitution are considered in the third and fourth sections.

SUBSTITUTION BY PRODUCERS

Substitution decisions by producers in the face of energy cost increases are fairly straightforward to analyse, since only simple cost minimization is involved. These kinds of substitution possibilities are implicit in any formulation of the profit maximization behaviour of a firm, and thus a lengthy description of such a model is not required here. Nevertheless there are several interesting questions that are not usually considered in traditional production literature but are of interest for this study; they therefore deserve some attention. The basic models are presented here, the more technical approach being relegated to Appendix B.

In any production process the cost of transportation of raw materials, goods in process, and the final product will be a determinant of the profitability of the firm. The importance of the costs of transportation will, of course, depend on the kind of good or service being produced and on the nature of the market in which the output is sold. One would expect transportation costs to be much

more important for the steel industry, for example, where both inputs and outputs are bulky and costly to transport, than for a retail jewellery store where the output is mainly service and where inputs are easily transported. The first and rather obvious conclusion, then, is that the extent to which gasoline price increases will affect the behaviour of firms clearly depends on the extent to which transportation is an important component of their overall cost structure.

When faced with a gasoline price increase any firm would be expected to seek methods of minimizing the effect of the now higher transportation costs. A variety of responses are possible, some of which have already been discussed. If the transportation of the final product is the principal component of transportation costs, it may be profitable for the firm to diversify production by setting up more plants so that customers can be more efficiently serviced. If inputs are the main source of transportation costs, it may be profitable to centralize production and/or relocate production closer to the input supply.

Other less dramatic changes may also result in cost savings. While fuel is certainly an important component of transportation costs, other inputs, in particular capital and labour, are also important, and it may be possible to rearrange the combination of these factors so as to reduce the cost increases associated with fuel price increases. These are the kinds of substitution that are considered in this section. In order to keep the model simple it will therefore be assumed that no relocation or other change in production takes place.

There are two kinds of substitution that could be considered by the firm attempting to reduce costs: substitution to other types or modes of transportation and substitution among the factors of production for a particular type of transport facility. To examine these and to illustrate how both may allow substantial cost savings in the face of higher gasoline prices it is convenient to introduce the notion of a production isoquant. This construct is a method of showing the relationship between a level of output (in this case the transportation of a certain commodity a certain distance) and the inputs required to produce this output. In Figure 5 two inputs, labour and gasoline, are measured on the vertical axis and horizontal axis, respectively, and the two curves R and T represent two types of isoquant for transportation of a given commodity a certain distance. The isoquant R illustrates the case where there is no substitution possible in the production process. Whatever the prices of labour and gasoline, L_0 of labour and G_0 of gasoline are required. The isoquant T illustrates the case where various combinations of the inputs L and G could be chosen to produce the level T of transportation.

With given prices for L and G the cost line can also be included in Figure 5. Thus for a certain level of cost C_0 and price of L equal to P_l, a quantity of labour equal to L_1 could be hired. Similarly with C_0 and price of gasoline P_g, G_1 of

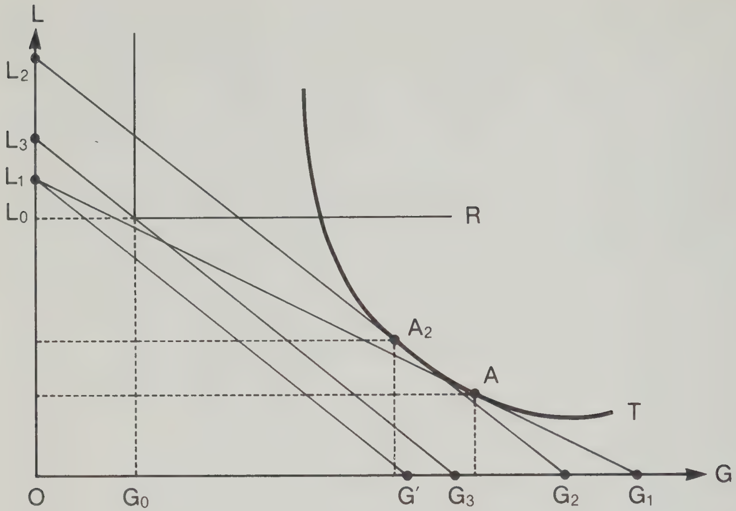


Figure 5

gasoline could be purchased. The line L_1G_1 represents all the combinations of labour and gasoline which could be purchased for the cost C_0.

Now suppose that the isoquants T and R represent two different types of transportation. Assume that T represents transportation by truck and that substitution between the two factors is possible by driving faster or slower. At higher speeds more gasoline is used, but since the travel time is shorter, less must be spent on labour costs for the driver. Let R represent transportation by rail, where, since train crews are paid by distance travelled rather than by time, no substitution between L and G is possible. There is thus some optimal train speed, and at any other speed more gasoline will be used than is required for efficient operation. With the cost line L_1G_1 it is clear that truck transport will be chosen over train, since a higher cost would be required to move the commodity by rail. For the prices given, point A represents the point where travel costs are minimized for the firm.

Now suppose the price of gasoline increases so that for C_0 the cost line becomes L_1G'. Clearly at these prices the expenditure of C_0 is not sufficient to provide the amount of transportation required. To reach the required level of transportation by truck an expenditure of C_1 would be required, moving the cost curve out to L:G_2, resulting in A_2 as the cost minimizing allocation of L and G.[1]

1 Because the price of L has not changed, distances on the L axis show relative total costs of providing the transportation T. Thus the cost associated with L_2G_2 will be twice that of L_1G_1 if OL_2 is twice OL_1.

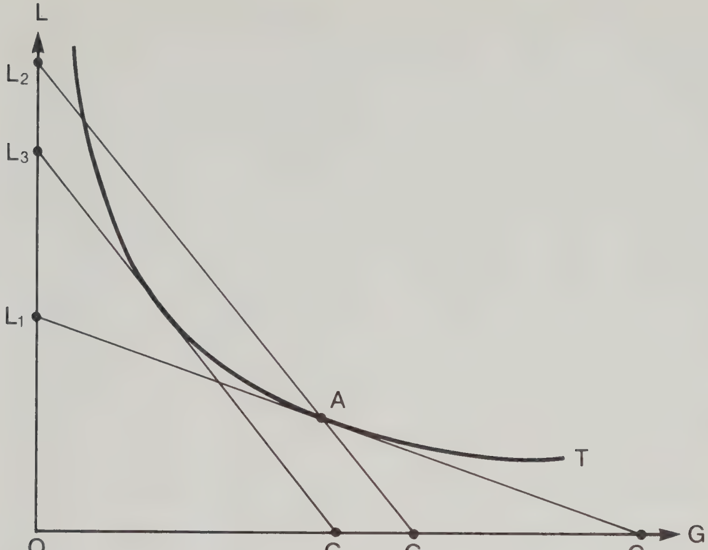


Figure 6

Note that with the higher price for gasoline, substitution away from gasoline and towards labour will be required for cost minimization. This would be accomplished by driving more slowly.

It is clear, however, that with the new higher gasoline price, substantial savings could be achieved by switching from truck transport to rail. For rail, a cost of C_3 represented by L_3G_3 would suffice, and this is clearly a lower expenditure than that associated with cost line L_2G_2. In this case it can be seen that substantial savings can be achieved by switching from one transportation mode to another.

Even in cases where switching modes is either not possible or not profitable, substitution may still produce substantial cost savings. Such a situation is shown in Figure 6, where the initial cost line is L_1G_1 giving rise to a cost minimizing equilibrium at A. Suppose gasoline price increases result in a price ratio equal to the slope of L_2G_2. If the firm is unable to substitute or for some reason chooses to produce the level of transport services T with the combination of labour and gasoline given by A, then costs will rise to L_2G_2, almost double the costs associated with the cost line L_1G_1. However, if the firm takes advantage of the substitution possibilities, the same level of transportation services could be provided at the cost L_3G_3. It is clear from Figure 6 that the more substitution there is in the production of transportation (the 'flatter' are the isoquants) the less the cost of transport will rise when gasoline prices rise.

The above observations have several important implications for the effect of gasoline price increases on urban structure. It has been observed at several points that when gasoline prices increase there will be a tendency for firms to relocate in order to minimize their total transportation costs. Firms may choose to move to the suburbs, for example, if trucking costs to outside markets make up an important component of transportation costs. The discussion here suggests that this tendency will be tempered by a number of influences. First, of course, if transport costs are a minor part of total costs, little relocation is to be expected. Second, if alternative modes of transportation are available, the effects of fuel price increases may be substantially reduced. And finally, if substitution within the transportation production process is possible, the cost increases associated with higher fuel prices will be further dampened. All these factors inhibit the tendency for higher gasoline and other fuel prices to encourage industrial relocation.

SUBSTITUTION TO ENERGY-EFFICIENT AUTOMOBILES

When consumers are faced with higher gasoline prices, they would be expected to react much like firms and find methods of substituting away from the higher priced commodity. Indeed in some respects the problems are quite similar. The household can be seen as combining capital (the automobile), labour (driving time), and gasoline to produce the transportation service necessary to undertake the journey to work. As was the case with the firm, savings could be achieved by substituting labour for gasoline with the given capital stock (driving slower) or by changing the capital and using a different technology (shifting to more fuel-efficient cars or to alternative travel modes). This section considers shifts to more efficient cars and the next section investigates shifts to other modes. Substitution in the consumers' production of transportation is considered in Appendix B.

While the producer and consumer problems are superficially similar, there are fundamental differences. The producer problem was to minimize cost where gasoline was one of the components of the cost function. The consumer is assumed to maximize utility, but gasoline is not a commodity that directly increases consumers' welfare. It was argued above that the consumer uses the gasoline to produce transportation services, but even transportation is not an element of the consumers' utility function.[2] While neither gasoline nor the

2 This is not to say that travel cannot increase utility, since recreational travel will certainly be an element of the consumer's utility function. The travel being considered here, however, is the basic journey to work; for most commuters this travel does not increase welfare.

journey to work provide utility, it is clear, however, that the automobile used to travel to work does. Consumers very clearly value features such as power, style, speed, and comfort. Furthermore, in general, these characteristics vary directly with the amount of gasoline used per mile, since larger, more powerful, and more comfortable cars have a lower mpg rate. It is thus clear that in order to conserve on gasoline the consumer will be required to substitute away from these characteristics.

It is at this point that we must part company with the standard journey-to-work model developed by Muth (1969). In the Muth model consumers are assumed to obtain utility only from housing services, q, and a composite of all other goods, x. Because the services of automobiles, defined here as z, are not specifically included, the model does not allow for the kind of substitution described above. It is, of course, simple enough to include the variable z in the utility function. It transpires, however, that what might seem to be a rather modest change in the specification of the model complicates the analysis significantly. The principal simplifying feature of the Muth model is that travel costs do not directly affect variables in the utility function but enter only through the budget constraint. Thus the direct effect of higher travel costs is to reduce disposable income. As is shown in Appendix B, this makes the maximization problem straightforward, and allows a solution to the problem of the determination of an equilibrium in the general urban model. Unfortunately the Muth specification also precludes an examination of the kind of substitution that is of interest here. Nor is this difficulty easily solved, since the inclusion of variables to allow for the consideration of substitution destroys the simplifying feature of the model that made a general solution possible.

But while a general solution is difficult or impossible, it is shown in Appendix B that the equilibrium condition of interest is still easily derived and is quite similar to the condition for the Muth model. In particular, in equilibrium the slope of the rent function must equal the slope of the travel cost function, and these two curves can be represented in a simple diagram. Even more care must be taken in interpreting these curves, however; for now not only will the Q curve be shifted by the indirect effect of changes in transportation costs, it will also be directly affected by the effects on the variable z.

As was the case for the Muth model, households will locate at a point where the slope of the rent function, represented by curve Q in Figure 7, is equal to that of the marginal travel cost function. As is shown in Appendix B, since total travel cost is assumed proportional to distance, the marginal cost function is constant (i.e., not affected by distance) and is written as $c(z, p^g)$. From Figure 7 it can be seen that in equilibrium the household will locate at a distance u_0 from the CBD.

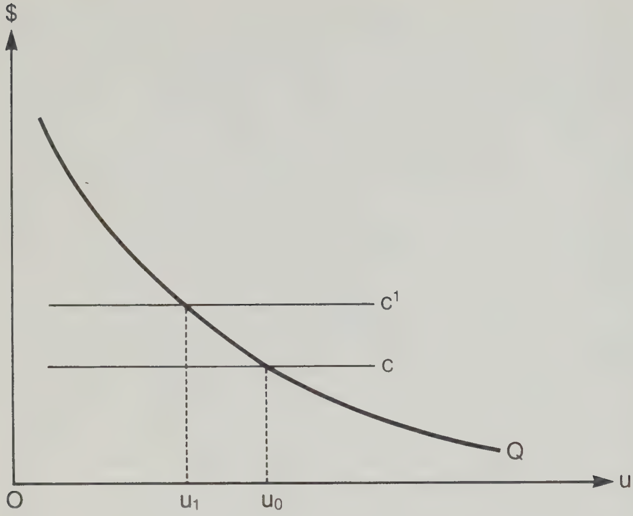


Figure 7

Now suppose there is an increase in p^g. This will tend to increase c, and if it were assumed that there was no substitution between z and p_g,$c(z, p_g)$ would shift up in proportion to the increase in p_g, and the result would be essentially the same as in the corresponding Figure 3 of Chapter 4. With substitution assumed between z and p_g, the amount that c will increase will depend on the nature of the cost function, on the degree of substitution that exists between z and p_g, and on the importance of z in the utility function. Suppose, for example, that unit cost as a function of z and p_g is as shown in Figure 8, where in the initial equilibrium the price of gasoline is $p_g{}^0$ and the services of the automobile z^0, giving a unit cost of c^0. Now suppose the price of gasoline increases to $p_g{}^1$. If the same automobile is retained, unit costs will increase to c^1, resulting in an increase in the marginal cost function of Figure 8 to c^1. This, in turn, would result in a new equilibrium location at u_1.[3] Alternatively, suppose that with the gasoline price rise the commuter purchases a smaller, more energy-efficient car, providing services at the level z^1. This would leave the unit cost per mile unchanged, and thus there would be no shift in c of Figure 7.[4]

3 There will also be a shift in Q. In general, the direction of the shift is indeterminate and thus Q has been left unchanged. Note that in this case, because of the presence of z in the utility function, the possibility of Q shifting enough to more than offset the shift in C cannot be ruled out. Thus U_1 could lie to the right of U_0.

4 This depends on the assumption that Q does not shift.

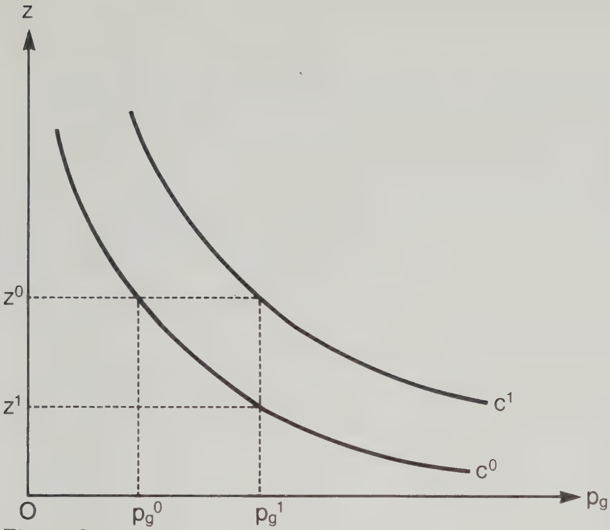


Figure 8

Of course neither of these polar cases could be an equilibrium, for unlike the models of Chapter 4, Figure 7 is not independent of the utility maximization problem, since the utility for each individual will depend on the level of z. If, with an increase in p_g to $p_g{}^1$ the level of automobile service is retained, it is clear from the budget constraint that the levels of x and q must fall, and the consumer would no longer be in equilibrium. Alternatively if the level of z is reduced to z^1, the conditions for a utility maximum would again be violated, because with unchanged prices for x, q, and z, the new level of z would be too low. Thus with the new higher price for gasoline, one would find both a reduction in z and an increase in c, the relative amounts depending on the nature of the function c and on the importance of z in the utility function. Should the consumer attach a very small weight to the extra services provided by a larger automobile, one would expect most of the adjustment to take place in z, resulting in a small upward shift in c in Figure 8. Alternatively, if the individual values his car above all else, one would expect a significant increase in c in Figure 5, resulting in a move towards the CBD to restore equilibrium. The issue of which effect will predominate cannot be answered from a theoretical analysis, and of course different individuals will have different relative preferences for the three goods. The empirical evidence reviewed in Chapter 7, however, suggests that the bulk of the adjustment will take place in the variable z.

THE EFFECTS OF TECHNICAL CHANGE

In the model so far described there will remain some tendency for households to relocate towards the CBD even if consumers switch to more efficient cars. This results from the fact that a large enough reduction in z to offset completely the increase in p_g and thus have disposable income unchanged would result in a situation where the household would be consuming too little z relative to the quantities of x and q. To re-establish equilibrium and maximize utility z must increase somewhat and x and q would be reduced. Of course, the increase in z would increase c, resulting in some tendency for the household to relocate closer to the CBD.

This model has implicitly assumed, however, that the automobiles themselves are unchanged, and that in order to obtain better gas mileage consumers must switch to smaller, less powerful cars. In other words, the analysis has not considered the possibility that technological improvements in automobiles of all classes could, over time, allow consumers to achieve higher gas mileage while at the same time retaining the same vector of characteristics, z. In fact, substantial improvements in automobile efficiency have been observed; indeed, government regulation has insisted on quite substantial gasoline mileage improvements. It thus seems worth while to examine how such technological changes would affect the analysis.

The effect of an increase in efficiency for all cars can be examined through a reinterpretation of Figure 8. Note that an increase in efficiency for an automobile providing a level of services z could be represented by a shift of the unit cost curve of Figure 6 from c^0 to c^1, where these two curves now represent the same level of cost, but different technologies. With the old technology c^0 and gasoline price $p_g{}^1$, the level of services z^1 could be enjoyed for a particular level of unit cost. With the new technology c^1 and the same price of gasoline, a higher level of automobile services z^2 could be enjoyed for the same expenditure. Alternatively, the same level of services could be enjoyed at smaller unit cost.

Now assume an initial equilibrium where with gasoline prices $p_g{}^0$ and technology represented by c^0, z^0 services of automobiles are consumed. Suppose that the price of gasoline rises to $p_g{}^1$, while at the same time technology improves so that the same level of unit travel cost is now represented by c^1. Obviously this new situation (i.e., z^0 units of automobile services and gasoline price $p_g{}^1$) is an equilibrium, since consumer disposable income is unchanged, and exactly the same quantities of x, q, and z are being consumed as well in the initial situation. Note that in this case there is no tendency for the household to relocate.

Of course the possibility that a technological improvement will exactly offset the gasoline price increase is extremely unlikely and simply represents a border-line

case. If technology is changing faster than gasoline prices, the new unit cost curve will be further to the right of c^1. In this case the same level of z can be enjoyed at a lower unit cost, and the total travel cost for the consumer actually falls in spite of the increase in gasoline prices. Here the equilibrium level of c in Figure 7 will fall, and there will be an incentive for the household to move further from the CBD, resulting in a reduction in urban density. Should gasoline price increases outstrip improvements in technology, unit travel cost will not shift out as far as c^1, and there will be pressure on individual households to move closer to the CBD, as was analysed above.

SUBSTITUTION TO ALTERNATIVE MODES

The third section of this chapter considered the case where consumers respond to gasoline price increases by reducing the quantity (or quality) of automobile services they consume. Another possible reaction when faced with an increase in the cost of automobile travel is to shift to some other mode of transportation, such as a bus or rapid transit system. Such a change represents a switch in travel technologies and thus is not unlike the kind of technological switch discussed for producers in the second section.

The motivation for such a switch by consumers is somewhat different from that for the switch to smaller cars discussed in the third section, since while buses and trains typically do not provide the same quality of transportation as an automobile, the principal reasons commuters continue to use cars is not the quality of the service but rather the time costs involved. As will be seen in Chapter 7, the high time costs of travel by bus and other forms of public transit are the main reasons for the preference for travel by private automobile.

The fact that time is the principal factor determining the choice between automobiles and public transit means that yet another model is required. If time costs are the principal determinant of the consumer's choice, the model must incorporate a time variable in the utility function. This is most conveniently done by including leisure as one of the 'commodities' over which households make choices. Thus in the model of this section the three variables in the utility function are q, the quantity of housing, x, all other goods, and l, leisure. This model is formalized in Appendix B.

The basic hypothesis of this model is that travel by automobile is significantly quicker than travel by any other means, and thus commuting by automobile maximizes the amount of time the household is able to spend on leisure activities. There is, of course, a trade-off between leisure and other commodities, and as the price of gasoline rises, the cost of leisure time increases in terms of the amount of other commodities that must be forgone. Specifically, as the price of

gasoline rises, travel costs rise proportionately (substitution to more efficient automobiles is assumed not possible here) and the amount of income available to purchase *all* commodities is reduced. The consumer is always able (it is assumed) to reduce his expenditure on travel substantially by giving up leisure and switching to the public transportation system. When or whether such a switch will take place will depend on how the household values the leisure time of the commuter, how much leisure will be lost (how efficient the public transportation is), and the differential cost between driving and taking the public transit. As will be seen in Chapter 7, time seems to be valued quite highly by commuters, and thus one would expect that very substantial increases in gasoline prices would be required to bring about a significant shift away from cars and towards the public transit system.

Assuming that some substitution to public transit does take place, it is easy to see what the effects on the conclusions of the standard journey-to-work model will be. When faced with higher gasoline prices commuters now have an alternative to moving closer to the CBD, namely switching to public transit. If housing services and lot size are very important to the consumer relative to leisure, the effect of gasoline price increases on urban structure and density may be significantly moderated. One would expect there to remain some tendency for a contraction of the size of the urban area and increases in the rent gradient, however, unless there are simultaneous improvements in the public transit system. Note, however, that such improvements would need to be of the time-saving variety, and such technological change seems more unlikely (at least for most urban areas) than the kind of technological improvement in efficiency that is occurring in the automobile sector.

It is worth noting that the two models presented in the third and fifth sections need not be viewed as competing explanations of the effects of gasoline price increases, since many individuals will simultaneously be considering both alternatives. A more general model would thus be a combination of both kinds of effects. Nevertheless, there may be identifiable situations where one model is of more relevance than the other. Consider, for example, a circular city defined by three concentric circular areas. The first is the CBD where all industry is located. The second defines the central city characterized by high density housing and inhabited mainly by lower and middle income families. The third contains the suburbs inhabited mainly by higher income families. It may be reasonable to assume that a higher proportion of lower and middle income families is, in the initial situation, already driving energy-efficient automobiles than would be the case in the suburbs. For such families the only choice open when faced with higher gasoline prices is a switch to an alternative mode of travel. If it is assumed that the first model dominates in the suburbs and the second is most relevant for

the central city, the overall effect on the urban density function of an increase in gasoline prices would be to make it more convex from above. The density gradient would become more steep near the CBD and flatter in the suburbs.

SUMMARY

In Chapter 4 a variety of models were examined in which producers and consumers reacted to gasoline price increases by relocating. For consumers, and assuming that CBD was the principal source of employment, there was found to be a tendency for households to move towards the CBD, thus increasing urban density and increasing the slope of the rent gradient. For industries no general relocation tendency could be established, but it seemed clear that at least for some firms moves to the suburbs would reduce costs and therefore increase profits. This chapter has considered an alternative reaction to gasoline price increases, namely the substitution to other forms of transportation or travel.

For the producer the analysis was straightforward, since the standard model of profit maximization assumes that transportation costs would be minimized, other things being equal. The specific response by producers will take the form of either substitution between gasoline and labour or substitution to another transportation mode (substitution between gasoline and capital) or, of course, both. The extent to which such substitutions are possible will temper the tendency of firms to move from the CBD to the suburbs.

For consumers such substitution possibilities are somewhat more difficult to analyse, because in the formulation of the utility function the standard model does not include arguments which allow the consideration of such substitutions. Although no great difficulty is encountered in formulating models that include the appropriate variables, the models become significantly more complex, and in general it is no longer possible to solve them explicitly. Nevertheless, it is relatively easy to show how these substitution possibilities will temper (and perhaps offset) the conclusions of the simple journey-to-work model of Chapter 4.

Two types of substitution were considered for consumers: substitution to more fuel-efficient automobiles and substitution to alternative modes of commuter travel. In the former, consumers are assumed to have the services of automobiles as arguments in their utility functions, and the level of these services is assumed to be directly related to the quantity of gasoline used. Thus, when gasoline prices rise, consumers can reduce the impact on travel costs by substituting away from automobile service, that is, by switching to more fuel-efficient cars. Technical change, in the form of development of more fuel-efficient cars that provide the same level of services, will further expand the substitution possibilities open to consumers. Obviously the combination of switching to

smaller cars and rapid technological improvement in all types of cars could completely offset the tendency for a specific household to move closer to the CBD when faced with a gasoline price increase.

The second type of substitution involves switching to an alternative mode (such as a bus or the subway), and in this case the principal determinant of the mode of travel is seen to be the time cost involved. To incorporate this factor explicitly into the analysis it is assumed that leisure is an argument in consumers' utility functions and that a switch to bus travel from private automobiles would increase the time of travel and thus reduce the time available for leisure. As gasoline prices rise (and assuming that no other substitution possibilities are open to the household), the commuter is faced with either the reduction in consumption of all other commodities (including housing services) or, if a switch is made to an alternative travel mode, a reduction in leisure time. The extent to which consumers do switch to alternative modes will again determine the extent to which the tendency to move so as to offset higher travel costs is reduced.

6
Policy simulations of theoretical models

INTRODUCTION

In this chapter some explicit theoretical residential location models are developed. This exercise has two purposes; the first is to model explicitly some of the issues discussed in Chapter 4, and the second is to parameterize the models using empirical evidence in order to 'simulate' various scenarios. The purpose here is to identify possible magnitude of responses of urban structure, in the short and long run, to changes in the price of gasoline. Although the models developed here are greatly simplified abstracts of reality, they will allow us to gain some basic insights into how increases in gasoline prices could be expected to affect urban structure under various scenarios. In addition, our simulations will provide some 'ballpark' estimates of possible magnitudes of response.

Before beginning, it may be useful to describe the nature of the simulations and their interpretation. The first model considered is the standard journey-to-work model. It has all the limitations described earlier, of course, but we hope that the reader was persuaded as to the utility of this simple model by our discussion in Chapter 4. In addition, economists have found the journey-to-work model very useful in describing broad attributes and trends in urban structure, and a considerable amount of interesting empirical work has been based on this sort of model (see Mills, 1972). Nevertheless, it is important to keep in mind that such models are long-run equilibrium models, in that urban structure is allowed to adjust fully to (stationary) economic factors. The first set of simulations presented in this chapter will show what happens to urban structure (in the long run) under various travel cost (gasoline price) change scenarios. The approach here is similar to that of Robson and Scheffman (1979) and Small (1981), except for an attempt to identify critical parameter values from Canadian data. It will be shown how *long-run* urban structure, property

values, and aggregate commuting travel vary under different travel cost scenarios for a menu of plausible parameter values.

This first exercise attempts to shed light on possible *long-run* effects of gasoline price increases on urban structure. In the short run the existing infrastructure is in place and can change only very slowly. Therefore the major adjustment in the short-run takes place in the pattern of new development (infilling, renovation, and new suburban development) and in the *valuation* of the existing structure. The second set of simulation exercises presented in this chapter simulates these short-run effects for various gasoline price scenarios.

This chapter concludes with a discussion of how travel substitution possibilities would be expected to temper the predictions of the earlier simulation exercises.

THE STANDARD JOURNEY-TO-WORK MODEL

Long-run model

This section will begin by describing a simple version of the standard journey-to-work model that will be used in the simulations (the technical details are provided in Appendix C). Then the model will be parameterized with plausible parameter values, and some simple simulations will be performed. The reader will recall from the summary of such models in Chapter 4 that each resident is assumed to live outside the CBD and commute every working day to the CBD. The city is located on a featureless plain, so that there are no topographic features that would distort residential values or densities. It is assumed that the city is made up of N identical residents (households), and each resident has a yearly (after tax) income of y. For simplicity, it is assumed that the sorts of goods that the residents consume can be dichotomized into two types: urban land and other goods. The price of the composite non-land good is taken to be unity.

To keep the calculations simple, it is also assumed that the residents living closest to the CBD face no commuting costs. Then, the cost of commuting from a distance u from the CBD will be denoted $t(u)$, and the income net of travel costs of a resident at distance u is $y - t(u)$. In order to determine the value of land at the periphery of the city, an exogenously given opportunity cost of land (say, the value of land used in agriculture) must be specified. The opportunity cost rent per acre will be denoted r. The final information necessary to close the model is the specification of the consumers' preferences for land and other goods, summarized by the utility function $U(x, q)$.

A stylized description of the equilibrium can be given, using the rent gradient diagram of Chapter 4, reproduced here as Figure 9. In Figure 9 a postulated rent gradient, $r(u)$, and the opportunity cost rent r are depicted. If $r(u)$ is the equilibrium rent gradient, then u^* is the furthest distance from the CBD that

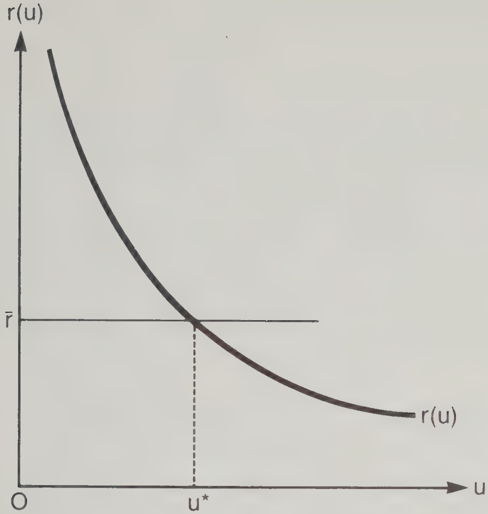


Figure 9

residents are located. For $r(u)$ to be the equilibrium rent gradient each of the identical residents must be equally well-off and the total amount of land demanded by the N residents given rent gradient $r(u)$ must be equal to the total amount of land available for residential purposes within a distance of u^* of the CBD.

In order to do simulations of the model particular functional forms for preferences, $U(x, q)$, and the travel cost function, $t(u)$, must be specified. It will be assumed that consumer preferences are such that consumers always spend a constant percentage, β, of their income, after tax, net of travel costs, on land. This assumption is very convenient computationally, and empirical work on consumer demand functions indicates that preferences modelled in this way are reasonably consistent with actual consumer demand, especially for aggregative models. A consumer with these preferences and net income $y - t(u)$ will spend β per cent of his net income on land and $1 - \beta$ per cent on the non-land good.

Finally, it is necessary to specify attributes of the supply of residential land. The expression $\theta(u)$ will denote the percentage of land available for residential purposes at distance u from the CBD.

In summary, the parameters to be specified in order to simulate this version of the journey-to-work model are: y, after tax income; $t(u)$, travel cost function; β, proportion of after tax income, net of travel costs, spent on land; $\bar{r}$, opportunity cost of land; $\theta(u)$, proportion of land available for residential purposes at distance u from the CBD; N, city population.

The mathematical details of the simulation model are summarized in Appendix C.

Evidence on parameter values

The objective here is to present two stylized models representing two Ontario metropolitan areas (Toronto and London) with a baseline date of 1975. In 1975 average family after tax income in Ontario metropolitan areas was about \$12,500, so that will be taken to be the value of y. In 1975 the number of households in the Toronto metropolitan area was 925,000 and in London 104,000. These will be taken as the values of N. Aggregative empirical evidence suggests that the proportion of developed land used for residential purposes is about 0.5, the assumed value of $\theta(u)$ (see Berry et al., 1974). It is particularly difficult to quantify β and $\bar{r}$.

The parameter β, the proportion of after tax income spent on land, has been estimated to be between 0.015 and 0.03 for U.S. data (see Small, 1981). Whatever the value of this parameter, it has clearly increased in recent years. For example, the ratio of estimated land costs of new single-detached dwellings financed under the National Housing Act (Canada Mortgage and Housing Corporation) to average family income in Toronto was 1.2 in 1971, but in 1978 the ratio was 1.4. Our experience with the London and Toronto housing markets suggests that the CMHC-estimated land cost series probably underestimates average lot values. Since good Canadian data are not available, it was decided to use the estimates of careful U.S. studies corrected upward for the secular increase in house price / income ratio. Because the estimate of β cannot be precise and since the results are sensitive to the choice of β, it was decided to use two plausible values: $\beta=0.02$ and $\beta=0.04$.

The value of $\bar{r}$ (the opportunity cost of land at the periphery) is even more difficult to quantify (see Small [1981] for a discussion of the U.S. evidence). Again the choice has been to consider a number of values of $\bar{r}$. The choice of $t(u)$ is usually taken to be of the form $t(u)=tu$; that is, it is assumed that average and marginal travel costs are constant. This greatly facilitates calculation and is not too unrealistic. The average cost per mile of operating an automobile for urban commuting has been estimated to be about 18 cents (Transport Canada, 1979). Therefore it is assumed that $t(u)=tu$ and the average cost of commuting travel per mile is 18 cents. Tables 1 and 2 represent simulations of Toronto and London for 1975 for the parameter values given above and for a range of values for β and $\bar{r}$.

In Tables 1 and 2 r is the opportunity rent per acre of land, u^* is the equilibrium radius of the city, D/N is the average distance of a household from the CBD, $r(0)$ is the rent per acre at the boundary of the CBD, and N_4/N is the proportion

TABLE 1

Toronto, 1975
Parameters: $N=925\,000$; $y=12\,500$; $\theta(u)=0.5$;
travel costs = 18 cents/mile

r	u^*	D/N	$r(0)$	N_4/N
$\beta=0.02$				
25	16.9	5.6	16417	0.44
50	15.2	5.4	16437	0.44
75	14.3	5.5	17158	0.45
$\beta=0.04$				
25	28.0	8.6	6957	0.18
50	25.6	9.7	8147	0.18
75	23.9	9.7	8421	0.18

TABLE 2

London, 1975
Parameters: $N=104\,000$; $y=12\,500$; $\theta(u)=0.5$;
travel costs = 18 cents/mile

r	u^*	D/N	$r(0)$	N_4/N
$\beta=0.02$				
25	11.7	5.3	2036	0.46
50	10.0	4.8	2097	0.49
75	9.1	4.7	2221	0.51
$\beta=0.04$				
25	18.7	7.9	929	0.19
50	16.1	8.0	1088	0.21
75	14.3	7.2	1134	0.22

of households living within four miles of the CBD. Before simulating changes in the cities resulting from changes in gasoline prices, etc., it is useful to examine how well our simple model has replicated London and Toronto. For $\beta+0.02$ the simple model replicates Toronto fairly well. The equilibrium radius is reasonable and the average distance from the CBD is practically right on (actual average distance from the centre of Toronto has been estimated to be 5.8 miles – see Transport Canada, 1979). For London the model overestimates the size of the city. For example, the average distance to the centre of London (D/N) has been estimated elsewhere to be 3.4 miles (Transport Canada, 1979), and the simulated radius is clearly too large. One problem is that income levels have been assumed

TABLE 3

Toronto – gasoline price simulations
Parameters: $N=925\,000$; $y=12\,500$; $\theta(u)=0.5$

$\bar{r}$	u^*	D/N	$r(0)$	N_4/N
$\beta=0.02$, $t=22.6$ cents/mile				
25	14.2	4.2	24 059	0.56
50	12.8	3.9	23 404	0.56
75	12.1	4.1	24 577	0.57
$\beta=0.02$, $t=31.8$ cents/mile				
25	10.7	2.4	37 572	0.75
50	10.1	3.0	48 406	0.75
75	9.6	3.1	50 478	0.75
$\beta=0.04$, $t=22.6$ cents/mile				
25	24.4	8.2	12 694	0.25
50	21.8	7.5	12 080	0.25
75	20.4	7.6	12 556	0.25
$\beta=0.04$, $t=31.8$ cents/mile				
25	18.9	5.7	24 179	0.39
50	17.4	6.0	26 008	0.39
75	16.5	6.2	27 085	0.39

to be the same in London as in Toronto. A smaller level of income in London would produce a smaller city.

None the less, our simple model has crudely replicated the aggregative parameters of London and Toronto. Since the main purpose of this exercise is to simulate the effects of *changes* such as increases in the price of gasoline, the fact that the model does not 'exactly' replicate London and Toronto may not be of significant concern. In the simple model average distance from the CBD represents the average one-way commuting distance, since there is only radial travel in the simple model. Of course circumferential travel is of considerable importance in real cities. For example, across Canadian cities the ratio of radial to circumferential travel is approximately one to one (Transport Canada, 1979). Thus total commuting travel is approximately twice total radial travel. As an approximation, then, the average trip length will be assumed to be twice D/N. This approximation provides a good fit for Toronto, where the average commuting trip length has been estimated to be 10.9 miles (Transport Canada, 1979). In London the average commuting trip length has been estimated to be 7.6 miles (Transport Canada, 1979).

TABLE 4

London – gasoline price simulations
Parameters: $N = 104\,000$; $y = 12\,500$; $\theta(u) = 0.5$

$\bar{r}$	u^*	D/N	$r(0)$	N_4/N
$\beta = 0.02$, $t = 22.6$ cents/mile				
25	10.0	3.9	2 854	0.58
50	8.6	3.5	2 860	0.61
75	8.0	3.7	3 200	0.62
$\beta = 0.02$, $t = 31.8$ cents/mile				
25	8.1	3.0	5 742	0.76
50	7.1	2.8	5 680	0.78
75	6.6	2.8	6 014	0.79
$\beta = 0.04$, $t = 22.6$ cents/mile				
25	16.9	7.6	1 578	0.26
50	14.2	6.4	1 551	0.28
75	12.8	6.0	1 623	0.29
$\beta = 0.04$, $t = 31.8$ cents/mile				
25	13.5	5.2	2 777	0.40
50	12.0	5.4	3 142	0.42
75	11.1	5.4	3 370	0.43

The following sets of tables summarize the aggregate data from some simulation experiments in which the effects of increases in gasoline prices are examined under various scenarios. Tables 3 and 4 present data from an experiment in which all parameters other than gasoline prices are kept constant. In what follows it was assumed that gasoline costs were 4.6 cents per mile of the total travel costs of 18 cents per mile (this figure was arrived at by assuming a gasoline price of 69 cents – baseline 1975 – and fifteen miles per gallon). Thus a doubling of gasoline prices from the baseline increases travel costs to 22.6 cents per mile and a quadrupling of gasoline prices increases travel costs to 31.8 cents per mile. Notice that in these experiments it is the *real* price of gasoline that is being changed, since income is assumed unchanged.

Before comparing Tables 1 and 2 with Tables 3 and 4, perhaps it would be useful to describe more fully the nature of the experiment being conducted. The simulations underlying Tables 1 and 2 provide a stylized description of the Toronto and London metropolitan areas for 1975. The simulations underlying Tables 3 and 4 provide a stylized description of a scenario in which gasoline prices double or quadruple, with no change in the other basic parameters, under

TABLE 5

Toronto – effects of changes in P_g

Per cent change in P_g	Per cent change in u^*	Per cent change in travel	Per cent change in r (0)	Per cent change in N_4/N
100	−15.8	−27.8	42.4	27.3
400	−33.5	−44.4	194.5	70.0

TABLE 6

London – effects of changes in P_g

Per cent change in P_g	Per cent change in u^*	Per cent change in travel	Per cent change in r (0)	Per cent change in N_4/N
100	−14.0	−27.1	36.4	24.4
400	−29.0	−41.7	170.9	77.3

the assumption that the city has enough time to adjust fully (i.e., the existing infrastructure is able to adjust *fully* to the new gasoline prices). Such adjustment would, of course, require substantial demolition and renovation, so that the period of time for such a change to be effected would be expected to be of considerable length.

Now, what does a comparison of Tables 1 and 2 with Tables 3 and 4 reveal? For purposes of brevity, consider the case $\beta = 0.02$, $\bar{r} = 50$. Table 5 summarizes the differences between Tables 1 and 3 for this case.

To get the percentage change in (daily commuting) travel in Table 5 notice that D/N is one-half the predicted *radial* commuting round trip and it has been assumed that radial travel is one-half of circumferential travel.

Table 6 presents the same data for London for the case $\beta = 0.02$, $\bar{r} = 50$.

Of course Tables 5 and 6 by no means completely summarize the effects of increases in P_g. For example, residential densities increase at each distance from the CBD. One indication of this is the change in N_4/N. Also, since it is assumed that consumers spend β per cent of their income net of taxes and travel costs on land, the lot size at the edge of the CBD, $q(0)$, is equal to $\beta y / r(0)$. Therefore, the percentage change in residential density at the edge of the CBD is equal to the percentage change in $r(0)$, which is provided in Tables 6 and 7. (Recall that residential density at distance u is equal to the amount of residential land at distance u divided by lot size, $q(u)$, at u.)

Tables 5 and 6 show that the simple model predicts that a doubling or quadrupling of the price of gasoline, other parameters remaining constant, would have a significant effect on urban structure, land values, and travel.

TABLE 7

Toronto, 2000

Parameters: $N = 1\,830\,000$; $y = 20\,500$; $\theta(u) = 0.5$

$\bar{r}$	u^*	D/N	$r(0)$	N_4/N
$\beta = 0.02$, $t = 31.8$ cents/mile				
50	17.3	5.7	67 236	0.48
75	15.7	4.1	49 507	0.48
100	15.7	5.5	66 009	0.48
$\beta = 0.02$, $t = 40$ cents/mile				
50	14.4	4.2	96 910	0.60
75	13.8	4.4	103 531	0.60
100	13.1	3.9	93 179	0.60
$\beta = 0.04$, $t = 31.8$ cents/mile				
50	29.4	10.2	32 281	0.19
75	27.8	10.1	32 501	0.20
100	26.2	8.9	29 268	0.20
$\beta = 0.04$, $t = 40$ cents/mile				
50	24.7	7.9	49 269	0.27
75	23.4	7.8	48 837	0.27
100	22.1	6.8	43 321	0.27

However, Tables 5 and 6 should not be taken as definitive projections of the future of urban structure under various gasoline price scenarios. In the simple model *only* urban structure can adjust to increases in price of gasoline, since no other substitution possibilities are allowed. This issue was discussed thoroughly in Chapter 4 and will be addressed further below.

Another difficulty with the simulations underlying Tables 5 and 6 is that (real) income and population are assumed to be constant. Real income and population are growing and can be expected to continue to grow in many Ontario metropolitan areas. To take this fact into account, a set of simulations was run that used projected real income and population. In these simulations it was assumed that real income grows at 2 per cent per year and population projections for Toronto and London were derived from Transport Canada (1979). Using these parameters Toronto and London were simulated for the year 2000; the results are summarized in Tables 7 and 8.

Of course the simulations generating Tables 7 and 8 are extremely speculative. None the less, they do suggest that increases in income and population will counteract the effects of increases in gasoline prices on city size and average trip

TABLE 8

London, 2000
Parameters: $N = 190\,000$; $y = 20\,500$; $\theta(u) = 0.5$

$\bar{r}$	u^*	D/N	$r(0)$	N_4/N
$\beta = 0.02$; $t = 31.8$ cents/mile				
50	11.7	4.2	5 817	0.50
75	10.8	4.1	5 953	0.51
100	10.1	3.9	5 907	0.52
$\beta = 0.02$, $t = 40$ cents/mile				
50	10.6	4.5	11 732	0.61
75	9.3	3.2	8 719	0.63
100	9.3	4.2	11 625	0.63
$\beta = 0.04$, $t = 31.8$ cents/mile				
50	19.7	8.0	3 157	0.21
75	18.1	7.8	3 292	0.21
100	17.3	8.3	3 667	0.22
$\beta = 0.04$, $t = 40$ cents/mile				
50	17.0	6.3	4 655	0.29
75	15.7	6.1	4 788	0.29
100	15.1	6.7	5 374	0.30

length. However, increases in population reinforce the effects of increases in gasoline prices on densities. For example, taking as the baseline case for Toronto $\beta = 0.02, t =$ 18 cents/mile, the edge of the CBD increases by 443 per cent over the baseline. (The increase is 285 per cent for an increase of t to only 31.8 cents/mile).

How should the results of these simulations be interpreted? The models simulated allow only one substitution response to increases in gasoline prices: changes in residential densities. Not surprisingly, if changes in densities are the only vehicle for change, densities and the associated variables such as city size and residential values will have to change significantly. However, as discussed in Chapter 4 and elsewhere in this study, there are other important substitution possibilities besides changes in residential densities. Commuters can turn to less gasoline-intensive travel modes in order to reduce on the impact of gasoline price increases on travel costs. Thus a doubling in the real price of gasoline may not increase travel costs by as much as the difference between 18 cents / mile and 22.6 cents/mile. This type of substitution will be considered again later in this chapter. In addition, as discussed in Chapter 4, employment location would be

expected to adjust to a higher gasoline price scenario. Our simple simulations assumed that employment would remain equally CBD-oriented in the future. This assumption seems particularly implausible for Toronto, if Toronto is to grow to the extent projected in the next twenty-five years.

Therefore the simulations presented thus far should be interpreted as strict upper bounds to the conceivable long-run adjustment of urban structure to increases in gasoline prices.

Short-run model

In the previous section the long-run effects of increases in gasoline prices were simulated. In this section short-run effects are simulated. What would the short-run effects be? In the short run most of the existing infrastructure will remain unchanged. Short-run effects will occur through demolition, renovation, new suburban development, and the revaluation of residential real estate.

In what follows it will be assumed that all residents are renters, so that for the time being the effects of changes in gasoline prices on the more wealthy can be ignored. Assume that the city is growing, so that there is demand for new residential accommodation. Assume further (as is realistic) that existing structures can adapt only marginally to the impact of gasoline price increases.

Tables 9 and 10 describe the results of simulations in which the price of gasoline doubles or triples from the baseline 1975 situation but the existing infrastructure has not yet been able to adjust. In these tables $\hat{r}(0)$ is the rent per acre of an *existing* lot at the edge of the CBD, $r(0)$ is the rent per acre of a *new* (smaller) equilibrium size residential lot at the edge of the CBD, and $\hat{r}(u^*)$ is the rent on an existing lot at the boundary of the city.

In order to assess the short-run impact of a doubling or quadrupling of the price of gasoline Table 10 should be compared with Table 4 and Table 9 with Table 3. Notice that there is a dramatic increase in the rent at the boundary of the CBD and virtually no change at the edge of the city. Also, existing residential lots at the boundary of the CBD sell at a considerable discount *per unit of land* relative to the price a newly created lot would command (compare $\hat{r}(0)$ with $r(0)$ in Tables 9 and 10). This is because existing lots are too big, given the new higher gasoline prices.

What is the nature of the experiment being conducted here? What is being considered is an *unexpected* dramatic change in the price of gasoline (e.g., the effect of OPEC). If future gasoline price changes were perfectly anticipated, current densities and values would reflect these future changes. However, real gasoline prices fell throughout the 1950s and 1960s, so that the intervention of OPEC could reasonably be argued to have caused a dramatic *unforeseen* increase in the price of gasoline.

TABLE 9

Toronto–short-run impact

$\bar{r}$	$t=22.6$ cents/mile $r(0)$	$r(0)$	$r(u^*)$	$t=31.8$ cents/mile $r(0)$	$r(0)$	$r(u^*)$
$\beta=0.02$						
25	45 468	99 547	25	103 503	4 503 726	24.9
50	42 238	81 040	50	93 788	2 315 003	49.8
75	42 315	76 021	75	92 583	1 716 467	74.7
$\beta=0.04$						
25	18 160	36 870	25	40 467	1 508 312	24.5
50	19 889	36 041	49.9	43 280	947 428	49.2
75	19 586	32 956	74.9	41 836	645 587	74.0

TABLE 10

London–short-run impact

$\bar{r}$	$t=22.6$ cents/mile $r(0)$	$r(0)$	$r(u^*)$	$t=31.8$ cents/mile $r(0)$	$r(0)$	$r(u^*)$
$\beta=0.02$						
25	4 429	6 690	25	9 210	78 881	24.9
50	4 176	5 708	50	8 331	45 002	49.9
75	4 210	5 485	75	8 185	35 185	75
$\beta=0.04$						
25	1 852	2 562	25	3 693	22 240	24.8
50	1 998	2 551	50	3 814	15 380	49.7
75	1 965	2 387	75	3 624	11 346	74.7

However, the results presented in Tables 9 and 10 must be qualified in a number of respects. First, the underlying experiment assumed the existing structure was fixed. The dramatic effects on rent on land near the CBD would strongly encourage demolition and renovation. Such expected changes are consistent with what appears to be occurring in central Toronto, where infilling and 'white-painting' seem to be major phenomena. It must also be realized that the entries in Tables 9 and 10 are (implicit) *rents*, not values. Projecting what would happen to values would be very complicated, but for many reasons the effect of energy price increases on values would be expected to be less dramatic than that on (implicit) rents. It is worth explaining why the simulations produced such a dramatic change in (implicit) rents. With an unexpected increase in gasoline

prices, land closer to the CBD will, not surprisingly, command a greater premium over land in the suburbs. If all residents are renters, they will bid up the rent on dwellings closer to the CBD, leading to the results depicted in Tables 9 and 10.

What is missing in this story is the fact that there are significant wealth effects resulting from the increase in gasoline prices. Residents with houses close to the CBD will find their houses increasing in value more than those of homeowners in the suburbs. Unlike the simple model where all residents are identical, even if originally the residents were identical, they no longer will be because of the differential imapct on wealth. Thus, for example, if land *values* changed by the same order as implicit rents in Tables 9 and 10, residents near the CBD, now being much wealthier, would, other things being equal, desire to move to the suburbs so that they could consume more land. This potential shift in residence would temper the change in land *values*.

Finally, of course, as with our other simulations, the models used here allowed no possibility for other forms of substitution in response to gasoline price increases. Since urban structure is assumed fixed, the only substitution possible is for (implicit) rents to change. Therefore, it is perhaps not surprising that the changes described in Tables 9 and 10 are so dramatic. Especially in the short run one would expect significant substitution towards less gasoline-intensive modes of travel. As was shown in Chapter 5, this sort of substitution loosens the linkage between travel costs and gasoline prices. As one crude approximation to the effects of substitution to less gasoline-intensive modes, the projected values for t could simply be corrected for projected increases in mileage. For example, one scenario could be a quadrupling of gasoline prices with an associated doubling of mileage, which would translate into a doubling of t from the baseline parameter.

None the less, urban structure is essentially fixed in the short run, and the change to OPEC-controlled oil prices was in all likelihood unexpected. Thus, although substitution in the form of more energy-efficient transportation is occurring at a rapid rate, these simulations do suggest that there will be significant short-run price effects on residential real estate.

SUMMARY

This chapter developed and simulated some specific versions of the standard journey-to-work model in order to characterize the possible effects of increases in gasoline prices on urban structure. Simple aggregative models were used, but an attempt was made to parameterize the models using Canadian data.

The simulations of long-run models suggested that significant increases in gasoline prices could have significant effects on urban structure – city size,

densities, and rent gradients. However, the long-run simulations must be interpreted with care. First, the long-run simulations assume a scenario in which urban structure can completely adjust to higher gasoline prices. Naturally, this would require massive demolition and renovation, so that the 'long run' contemplated in this scenario is very long indeed. Furthermore, the models developed offer little possibility for substitution towards less gasoline-intensive forms of travel. As argued in Chapter 5, such substitution would be likely to temper significantly the relationship between gasoline prices and urban structure.

The chapter concluded with some simulations of short-run models of urban structure. It was shown that significant unexpected increases in the price of gasoline (e.g., OPEC in 1974) could very well have significant effects on urban land values and on the pattern of new residential development. Casual empiricism suggests that the recent phenomena of 'white-painting' and higher density suburban development are consistent with this prediction. Again, however, to the extent commuters can change to less gasoline-intensive modes of travel in the short run, the short-run effects of increases in gasoline prices on urban land values and new residential development will be tempered. The combination of U.S. government fuel economy standards for new automobiles and an apparent shift in preferences towards more fuel-efficient automobiles already seems to be having a significant effect.

7
The empirical literature

INTRODUCTION

In Chapter 4 the basic journey-to-work model was described, and it was argued that critical to the effect of gasoline price increases on urban structure was the relationship between gasoline price increases and travel costs. Indeed, all the adjustments to urban structure and density were generated by changes in $t(u)$, the cost of travel. In Chapter 6 a number of simple simulations were described to illustrate how changes in $t(u)$ would affect urban density, the equilibrium size of an urban area, and the values of residential property. All these simulations presuppose that gasoline price increases do result in higher travel costs.

In Chapter 5 several models were presented that showed that substitution by consumers could substantially reduce or perhaps completely counteract the tendency for gasoline price increases to increase $t(u)$. It was argued that the combination of increased efficiency for all cars and substitution to smaller, more fuel-efficient automobiles could conceivably result in a situation where $t(u)$ was not increased or perhaps even lowered, even in the face of substantial increases in P_g. Another form of substitution discussed was substitution to other modes of travel, such as bus or rapid transit. Clearly it is very important to obtain some information on which of these alternative responses to gasoline price increases are to be expected in real world situations. Policy prescriptions cannot be formulated unless one understands in which direction gasoline price increases will move urban densities.

This chapter reviews some of the literature relevant to the effects of rising gasoline prices on changes in urban structure. The first relationship to be examined is the demand for gasoline and the corresponding price elasticity of demand. The literature in this area emphasizes the distinction between the long-run and the short-run elasticity. While each study differs somewhat in

methodology, the essential focus is on possibilities of substitution, the two most obvious avenues of substitution being from large to more fuel-efficient small cars and from personal automobiles to public transportation, or more technically, modal choice analyses. This chapter also summarizes some of the relevant literature on housing demand and supply.

Much of the literature, particularly that concerning the demand for gasoline, uses American or European data. There are two reasons for this. First, much of the more prominent work has been carried out by American economists, and second, European data exhibit more price variability than both Canadian and American data. Indeed, the stability of Canadian gasoline prices and the lack of cross-section data (ten provinces versus fifty-two states) do not provide a good data base for this type of analysis. Canadian studies cited in this chapter use pooled cross-section and time-series data. It seems safe to assume, however, that a good deal of similarity exists between the values of U.S. and Canadian elasticities.

The time span over which increasing prices of gasoline and the concomitant effects on behaviour are expected to occur is long enough to allow for the incorporation of income effects. All the studies incorporate personal income as an argument in the objective functions, and a full discussion of income elasticities is incorporated. Rising incomes are a large and important explanatory component of automobile ownership and cannot be ignored. The important new dimension to be considered is the possibility that gasoline prices will rise at a higher percentage rate than incomes.

THE DEMAND FOR GASOLINE

An important contribution to the literature on the demand for gasoline was the paper by Griffin (1979), who begins his analysis with a simple relationship between gasoline consumption, miles driven per automobile, gasoline consumption per mile, and the number of cars per capita. The resulting equation is simplified to show gasoline used per car as the product of automobile utilization and automobile efficiency, parameters that are more easily observed. The Griffin study also draws on earlier work by C.E. Scheffler and G.W. Neipoth (1965), who show that car weight (W) is a principal determinant of fuel efficiency.

In summary, Griffin finds income elasticities ranging from 0.77 for the United States to 1.77 for Turkey. For the price elasticity of gasoline demand, Griffin calculates a long-run value of –1.50 and a short-run value of –0.066. Since the price of gasoline constitutes only some 20 per cent of total user cost of operating a car and since per capita car ownership may be reaching a saturation point, it is likely, concludes Griffin, that much of the decrease in gasoline consumption is

accounted for by a switch to lighter, more efficient cars. Even though rising per capita income tends to increase gasoline consumption via an increase in average car weight, the income effect on gasoline demand, and the per capita ownership of cars, the long-run price elasticity of gasoline is greater in magnitude and opposite in sign. Thus, if gasoline prices are rising faster (at a percentage rate) than incomes, we would expect to observe a reduction in the consumption of gasoline through a switch to more fuel-efficient cars, with no reduction in and perhaps a slight increase in per capita car ownership.

Major contributions to the study of gasoline demand have been made by Houthakker and Verleger (1973) and Houthakker, Verleger, and Sheehan (1974). Houthakker and Verleger used cross-section data for the United States and found a long-run price elasticity of –0.75. Using quarterly data in a subsequent revision of the study, Houthakker, Verleger, and Sheehan obtained a short-run elasticity of –0.06 and a long-run elasticity of –0.24. These studies were based on samples with very low between-state variations. The studies also failed to take account of the change in car efficiency over time. A study by Verleger and Sheehan (1976) specifically incorporates such an adjustment.

Verleger and Sheehan treat demand for gasoline as a derived demand, derived from automobile usage and automobile demand. The demand for goods and services in general gives rise to a demand for transportation, of which there are two modes, public and private. The demand for private transportation is a function of its relative cost. This gives rise to the demand for gasoline, which in turn is a function of miles travelled and automobile services. Other factors such as income, weather conditions, and the price of autos will also influence the demand for gas. Verleger and Sheehan isolate what they consider to be the three main influences: (1) cost of operating a vehicle, (2) choice of vehicle type, and (3) income.

In the short run, the choice of vehicle type is fixed so that the short-run determinants of gasoline demand are (1) and (3). Verleger and Sheehan argue that the price of gasoline is a small proportion of the total cost of operating a vehicle but is a significant proportion of the variable costs of operating a vehicle. According to the FHWA *Report* (1972) the cost of gasoline is a minimum of 52 per cent of the variable cost of operating a standard-size auto, 49 per cent of the variable cost of operating a compact, and 43 per cent of the variable cost of operating a subcompact. 'Thus, while gasoline is not the only variable cost, it does represent a large share of the variable operating cost' (Verleger and Sheehan, 1976, 183).[1]

1 This view should be clearly distinguished from the commonly held notion that the price of gasoline represents only a small fraction of the *total* operating cost and therefore has little effect on the utilization of an automobile.

Verleger and Sheehan note that data on individual consumption of gasoline are not available and thus carry out their analysis at the aggregate level. However, at the aggregate level several factors that can be ignored in considering individual behaviour must be incorporated. Both the age and size characteristics of the stock of automobiles on the road and the population distribution should be included. Verleger and Sheehan report a high correlation between per capita gasoline consumption and population density. They also acknowledge the simultaneity problem of gasoline supply but ignore this fact, noting that the period for which the analysis is carried out was free from supply constraint problems.

Verleger and Sheehan claim that a dynamic adjustment model of consumption is the appropriate one for studies of gasoline consumption, because it reflects the dynamic opportunities for fuel economy open to the consumer, 'such as cutting the number of trips to the store, rearranging the use of autos to save gasoline and forming car pools ... In the long run inefficient cars can be replaced by smaller more efficient ones' (1976, 190).

The results of the Verleger-Sheehan study are published in extensive region-by-region detail, and only a summary is given here. The average short-run price elasticity of demand for gasoline is found to be –0.09, with a range of estimates ranging from –0.07 to –0.11. The average short-run income elasticity is 0.34, with a range from 0.28 to 0.40. The long-run price elasticity is roughly –0.45 with a range from –0.4 to –0.5, and the long-run income elasticity is 1. Verleger and Sheehan used instrumental variables and error components estimation methods, following Nerlove (1971).

Houthakker attributes the difference between these results and those of the Houthakker-Verleger (1973) study to the use of quarterly data. The long-run price elasticity figure of –0.75 quoted in the earlier study also shrank to –0.24 in a subsequent use of quarterly data by Houthakker, Verleger, and Sheehan (1974). The Verleger and Sheehan (1976) study discussed above differs from the Houthakker, Verleger, and Sheehan analysis because of the use of a different estimating procedure and a different time span for the data. The Verleger and Sheehan study represents the most methodical and systematic analysis in the group of studies by these authors and can be taken as representative of the dynamic consumption model studies.

The Griffin (1979) approach described above introduces investment in new automobiles in a dynamic framework in a three-equation model. James Sweeney (1976) extends this approach and introduces a capital stock adjustment model with eight equations. A further extension to include a market-share approach to capital stock adjustment is made in Cato, Rhodekor, and Sweeney (1976). Sweeney's work represents a more elaborate attempt to isolate the gasoline-saving reaction of gasoline demand to price increases. In his 1975 paper

Sweeney employs a vintage capital model with a stock adjustment framework in which fleet-wide average fuel efficiency changes slowly as new cars replace old ones. It thus contains equations that estimate the average efficiency of new cars in a given year, while other equations determine the number of new cars added to the stock each year and the removal rates of each vintage. The model also predicts a decline in the average vehicle miles of travel as each vintage ages, reflecting the tendency for new cars to be used more than old ones.

The dynamic price elasticities of gasoline demand implied by the Sweeney model are –0.22 for the first year, –0.50 for four years, –0.66 for nine years, and –0.73 for fourteen years. These price elasticities can be broken down into two components that decline over time and a 'fleet efficiency elasticity' that increases. These converge to a long-run equilibrium vehicle-mile elasticity of –0.06 and a long-run fleet efficiency elasticity of –0.72, which combine to produce a long-run price elasticity of demand for gasoline of –0.78. These estimates imply that while a doubling of gasoline prices would eventually reduce gasoline consumption by 78 per cent, almost all the decrease would be achieved through higher fuel efficiency. *The long-run decrease in vehicle miles per capita would be only 6 per cent* (notice, however, that the Sweeney analysis implicitly assumes that urban structure is fixed).

The contention of the Sweeney vintage capital model is that economy of gas consumption takes place through a change in the efficiency of the stock of automobiles in service. Sweeney makes a more detailed analysis of the relationship between sales of cars by size and the price of gasoline, income, and technology in Cato, Rodekohr, and Sweeney (1976), which serves as a useful entry point to the more specific discussion of the demand for automobiles.

One of the questions raised in Chapters 4 and 5 was the issue of how commuters would respond to gasoline price increases. The standard journey-to-work model suggests that the principal response will be the movement of households towards the CBD, while the substitution models suggested that this tendency could be dampened or perhaps completely offset by switches to more efficient automobiles and technological improvements in the automobile industry. The empirical literature that has just been reviewed lends strong support to the substitution alternative. All the studies suggest that the principal response to gasoline price increases will be switches to more energy-efficient automobiles. This in turn suggests that gasoline price increases will not be expected to result in significant changes in urban density. There will, of course, always be some tendency for households to move when faced with higher transportation costs. If, as has been suggested, urban structures respond only slowly to demand changes (see below under 'The demand and supply of housing') even modest increases in demand could result in significant changes in housing values and

rents. Thus, as shown in Chapter 6, a significant short-run effect on rents and housing values could be the most significant results of rising gasoline prices.

THE DEMAND FOR AUTOMOBILES

It has already been argued that the cost of gasoline represents some 20 per cent of total fixed costs and 50 per cent of variable costs of operating an automobile. One would therefore expect to see a shift in the distribution of demand towards more fuel-efficient vehicles with rising gasoline price. However, in the choice of automobile (by size classification) personal income is a highly influential factor, and rising incomes may offset the effect of rising gasoline prices. Furthermore, over time technology improves the fuel efficiency of cars in existing classifications, so the consumer can economize on fuel consumption without changing the classification from which he chooses his car. Such a 'technology' elasticity is incorporated into the Cato, Rhodekor, Sweeney (1976) analysis.

Sweeney et al. use automobile classifications based on characteristics, and group cars as they exhibit these characteristics.[2] The actual classification is based on a modification of the hedonic price index concept described by Griliches (1971). Having classified the cars into small, medium, and large, Sweeney et al. derive the demand for each classification. The analysis then proceeds to derive the demand for gasoline and automobiles and calculates elasticities of demand with respect to price, income, and technological characteristics. Short-run elasticities are for one year, and long-run elasticities are for twelve years.

As one would expect, all the own-price elasticities for automobiles are negative, with medium-sized cars being the most elastic and small cars being the most inelastic. The short- and long-run price elasticities for medium-sized cars are –2.67 and –1.73, respectively, while for small cars these elasticities are –1.67 and –0.83. All the cross elasticities are positive and relatively small, with the exception of three. The cross elasticity of the quantity of small cars with respect to a change in medium-sized car prices is 3.33 and 2.98 for the short and long run. This indicates that when consumers are faced with an increase in medium-sized car prices, they are much more willing to move down in class than they are willing to move up in class when faced with an increase in the price of small cars alone. The cross elasticity of large cars with respect to a change in medium-sized car prices and the elasticity of small cars with respect to large car prices are negative. It is argued that these results are due to a normalization scheme introduced in the classification process.

2 This approach follows Kelvin Lancaster (1966).

The technology elasticities show that an increase in the efficiency of all cars induces a shift from small cars to large cars, since large cars are relatively cheaper after the increase in efficiency. The elasticities of sales-weighted miles per gallon with respect to a change in the efficiency of small, medium, and large cars are all positive. The elasticity of new car sales-weighted miles per gallon with respect to a change in gasoline prices is 0.135 in the short run and increases to 0.301 in the long run. The increase in the elasticity over time reflects the fact that consumers demand more smaller cars when faced with higher gasoline prices. The elasticity of new car sales-weighted miles per gallon with respect to a 1 per cent increase in efficiency is less than one and equals 0.87 in the short run and 0.69 in the long run.

These results show that increasing efficiency of large cars will have a small effect on sales-weighted efficiency, since there are two offsetting effects. First, those buying large cars will experience improved efficiency and thus the sales-weighted efficiency will improve. Offsetting this effect, however, is a market share effect. This efficiency improvement will induce buyers to purchase more large cars and fewer medium- and small-sized cars. This effect *reduces* sales-weighted efficiency. The net result is only a small change in sales-weighted efficiency.

The income elasticities derived are positive, and as one would expect are highest for large cars, with short-run and long-run values of 4.7 and 1.44, respectively, The smallest income elasticity is 0.2 for small cars in the long run – again not a surprising result. Sweeney's estimate of the long-run price elasticity of demand for gasoline is –0.36 and the short-run value of –0.24 is a little higher than the values quoted in many previous studies. This difference is probably due to the fact that the 'short run' in this study is one year rather than one quarter.

A study that is set in a specifically Canadian context is that by Blomqvist and Haessel (1978), who also break down the demand for automobiles by size classification. Blomqvist and Haessel begin by studying the factors that affect the demand for the flows of services from each type of passenger car. The demand for passenger car services is then translated into an equilibrium desired stock of cars to be owned by consumers. Since there are costs involved in adjusting the actual stock to desired stock, a dynamic model in which adjustment to the desired configuration of car stocks takes place with a time lag is developed.

The authors use three estimation techniques – ordinary least squares, two-stage least squares, and a variance component method – ordinary least squares, two-stage least squares, and a variance component method – to derive short-run structural elasticities for the stocks of new large, new small, and old cars with

respect to prices of cars, income, and the price of gasoline. For new large cars both own and cross price elasticities are found to be very small, the largest own price elasticity being –0.65. The cross price elasticities for new large cars and new small cars are small and negative, the largest estimate (in absolute value) being –0.15; the cross price elasticities for old cars are small and positive, the largest being 0.64.

For new small cars the own-price elasticities are somewhat larger, the two-stage least squares estimate being –1.78. All new small cross price elasticities are positive for both new large car prices and old car prices. None, however, is greater than unity. All new car income elasticities are also very small, the largest being 0.53 for large cars. Gasoline price elasticities for new cars are also small and some (for small cars) are even positive. Blomqvist and Haessel conclude:

> in general, the demand for each type of car had a relatively high short-term elasticity with respect to its own price and in some cases also fairly high cross elasticities with respect to the prices of other types of cars. The partial elasticity of demand for new cars with respect to the price of gasoline was found to be relatively small; however, the demand for older cars was found to have a substantial elasticity with respect to the price of gas, and this, coupled with the high cross price elasticity of new car demand with respect to the price of older cars, indicates an important indirect effect on the demand for new cars of changes in the gas price, most of it affecting large new cars. (1978, 488)

It should be noted that the Blomqvist-Haessel study does not use data that exhibit as much variation as U.S. data do. Also, the elasticities that were calculated were short-run structural elasticities.

An author who has stressed the importance of income as a determinant of automobile ownership is John Kain (1969). He argues that most of the changes in auto ownership since 1900 are directly or indirectly traceable to income changes. He reports four regressions; a time series of annual U.S. data 1960–63, a cross-section sample for twenty-three OECD countries in 1958 and 1968, and a cross-section sample of sixty-eight non-communist countries with per capita incomes greater than $300 in 1970.

Kain's analysis shows that real income alone explains more than 80 per cent of the total variance in automobile ownership in all four specifications. Furthermore, all four of the widely different empirical samples yield large income elasticities, ranging from a low of 1.4 for the non-communist countries to 2.0 for the time series for the United States and for the 1958 OECD cross-section. These elasticities imply that a 1 per cent increase in real per capita income will result in a 1.4 to 2 per cent increase in per capita auto ownership.

Kain also presents car ownership statistics to illustrate further the importance of the relationship between income and automobile ownership. He notes that in

1974, while 97 per cent of all households with incomes over $25 000 owned at least one car (and 68 per cent owned two or more), less than 50 per cent of families with incomes less than $3 000 owned cars. In 1974, 15 per cent of all U.S. households did not own a car. This statistic, he suggests, is evidence that there is still substantial potential for further increases in automobile ownership.

Although the demand for automobiles was not a central issue in earlier chapters, the empirical literature surveyed here has important implications for the question of the effects of gasoline price increases on urban structure. For example, one would expect there to be a positive relationship between per capita automobile ownership and per capita miles driven. Although it is possible for an individual to buy a car and not drive it or for a family to buy a second car and drive less in total, it seems safe to assume that more cars imply more miles driven. It if had been shown that the principal determinant of automobile ownership was the price of gasoline, then increases in the price of gasoline would be expected to reduce automobile ownership and miles driven (and probably commuter miles per capita). No such relationship has been found, however, and instead the level of income has been found to be the dominant determinant of the demand for automobiles. If real income continues to increase and the per capita ownership of automobiles continues to rise, one might expect to observe more individuals driving to work in spite of higher gasoline prices. If income is the important determinant of automobile ownership, and if suburbanization is principally a function of automobile ownership, then rising incomes may well reduce urban density even in the face of rising gasoline prices. In any case this literature argues that other factors may swamp the effects of gasoline price increases, so that the hypothesis that gasoline price increases will result in smaller, more dense cities with steeper rent gradients may be questionable.

THE DEMAND FOR URBAN TRANSIT

The literature on urban transit follows two main theoretical lines in explaining the level of transit usage. One approach is to explain the level of usage as a commodity in the consumption bundle of the household, and the other treats public transit as a binary choice variable (along with private transport modes) and sets up a behavioural model of modal choice.

As an example of the demand approach, Oi and Shuldiner (1962) treat the demand for urban transit as a derived demand. The household's primary consumption activities give rise to a demand for trips to the workplace, for shopping, to leisure centres, etc. Oi and Shuldiner's study is concerned not so much with the effects of rising transit costs or private mode costs as with

geographical characteristics and car ownership levels. A recent and representative study of the demand style approach that uses Canadian data is one by M.W. Frankena (1978). This study starts from the hypothesis that the quantity of bus service demanded per capita in an urban area depends upon the money and time costs of travel by bus and by private automobile, average income, other socio-economic characteristics of the population, and geographical characteristics of the urban area.

In the Frankena study, bus rides per capita (*R/P*) is the dependent variable where *P* is measured for the area served by the transit system. Money cost per trip is measured by the adult fare per trip. Time costs of trips by bus are difficult to measure directly. Average walking (to the bus stop) and waiting time per trip by bus could be measured by the annual number of bus miles of service per square mile of area served (*M/A*). The argument is that if an urban area has more bus miles of service per square mile of area, it typically has a higher density of routes and/or more frequent service. Consequently, average walking time and waiting time per ride are generally lower in an urban area with more bus miles per square mile of area. In fact the data on population served are more reliable than those on area served; thus bus miles of service by population (*M/P*) is used as a proxy for time cost in the Frankena study. The price of the principal substitute for bus travel, the automobile, is included in the equation as four measures: an index of the real price of purchase of an automobile (X_1), an index of the interest cost of funds used to hold an automobile net of the capital gains on a non-depreciating automobile (X_2), the real price of gasoline (X_3), and population *P*, the latter being a crude proxy for speed of automobiles and parking time. Depreciation is proportional to X_1 and the net interest cost of holding an automobile is proportional to the product X_2X_1.

Geographical variables include a measure of the work-force employed within the CBD, a proxy measure being the female labour force participation rate as a percentage. Severity of the winter and precipitation are also represented in the regression equation. Casual inspection of the explanatory variables suggests that some variables, such as fare and bus miles per capita, are determined simultaneously with rides per capita. Thus a simultaneous model is also estimated. Estimates of the fare elasticity of demand for bus travel are –0.38 and –0.09, and elasticity with respect to bus miles of service per capita is 1.12 and 0.61 for the different estimations.[3] The coefficients on income are negative and significantly different from zero, suggesting that bus rides are an inferior good.

3 The first estimate appears high, since it suggests that the bus company would increase ridership by increasing fares and using the additional revenue to increase services.

Domencich and Kraft (1970) present another model emphasizing the demand approach. Their model differs in that the dependent variable is more restricted. Data were drawn from an origin-destination study for the Boston area in 1963 and 1964 constructed for the Boston Regional Planning Project; 43 000 households out of a universe of 800 000 were interviewed and estimations by restricted least squares for auto and transit trips for work and shopping purposes were carried out. The cost elasticities for auto trips were found to be –0.49 and –0.88 for work and shopping trips. The fare elasticity estimates for transit trips were estimated to be –0.323 for shopping trips and –0.19 for work trips. The cross elasticities were not significantly different from zero, and because of the constraints imposed, these can be taken as evidence for non-positive cross elasticities. An interesting feature of their results is that travel demand is far more responsive to reductions in travel time than to reductions in fares. For work trips, for example, the time elasticity for autos was –0.82 compared with a cost elasticity of –0.49. The time elasticity for transit work trips was –0.39 as compared with –0.19 for the cost elasticity. There is also some evidence that transit ridership is more responsive to improvements in collection and distribution service than to increases in line-haul speeds. The transit line-haul time elasticity for trips to work is only about half that for shopping trips.

Having summarized the demand style analyses of transit ridership, it remains to discuss the modal choice studies. The pioneering work in the application of binary choice analysis to choice of urban travel mode was done by Warner (1962). Warner concentrated on analysing the effect of trip times by various modes and trip costs and the incomes of users on mode choice. Through these influences the study aims to estimate the 'probability' that an individual will choose one or the other mode of travel. Quantifying the effects of the independent variables on the choice of mode makes it possible to make statements of a type analogous to those of conventional demand elasticities. Warner's study uses data from interviews of 2 100 households in the Cook County Illinois area in which a number of questions were asked concerning income, the age and sex composition of the family, and the choice of mode of transport given that a trip was desired.

A binary choice is defined for a certain population by identifying each member with one of two mutually exclusive responses. A collection of sample observations is drawn from the population. Each observation provides numerical values for a specified set of explanatory variables and knowledge of the choice made by that observation. The problem then is to estimate the relationship between the specified explanatory variables and the choice that is made. In a conventional regression model where the independent variables are taken as

fixed, an estimate of the way some continuous variable depends upon them can be obtained. Here, the problem is to estimate probabilities for fixed values of the explanatory variables.

McFadden (1973), McFadden and Reid (1974), and Domencich and McFadden (1974) have done empirical work based on binary choice analysis. The consumer's optimization problem is stated in terms of 'basic drives' and characteristics vectors for the transport modes. The relevant drives are assumed to be for nourishment, rest, and comfort. Estimation by maximum likelihood methods was carried out on data collected for a survey of the Bay Area Rapid Transit (BART) system. Estimates of auto-bus patronage and demand elasticities for East Bay area residents who commute to work were calculated, and the population's response to a three-way choice of car-bus-BART was also estimated. McFadden is reluctant to draw conclusions from the BART Impact Study but notes merely that the results are consistent with existing studies on travel behaviour. McFadden's results show a tendency for bus demand (and BART demand) to increase significantly with respect to car costs. Elasticities of 0.97 and 0.81 were reported. McFadden's estimate of the fare elasticity of bus demand is –0.45 and thus is somewhat high by usual standards. The elasticity for on-bus times was found to be –0.46 and is greater in absolute value than the car on-vehicle times elasticities calculated to be –0.13. For bus travel a walk-time elasticity of –0.17 and a transfer wait-time elasticity of –0.26 were also calculated.

The results pertaining to the demand for urban travel are, from the point of view of this study, somewhat inconclusive. Although some studies (McFadden's for example) have found that the cost of automobile travel is a significant determinant of urban transit use, others have failed to find such a relationship.

One significant result is the importance of the time cost as a determinant of use of public transportation. It was suggested in Chapter 5 that a determinant of whether people would use private automobiles or public transit was the leisure time cost of these alternatives, and the empirical results suggest that this was an appropriate specification. Unless public transit becomes more time efficient (or the private automobile less time efficient) one would not expect major shifts away from cars to public transit unless major real increases in gasoline prices are observed. It was also of interest to note that bus travel was found to be an inferior good. This further supports the conclusion of the previous section that higher incomes would be expected to lead to more automobiles and more miles driven.

THE DEMAND FOR AND SUPPLY OF HOUSING

Several empirical questions concerning the housing market are relevant for this study. Of particular interest are the questions of how the demand for housing

might be affected by increases in petroleum prices, and the question of how one would expect the quantity of housing to respond to increases in housing prices, that is, the magnitude of the price elasticity of supply of housing. The issue of the effect on the location of housing demand of increases in heating costs was raised in Chapters 3 and 4, where it was argued that the age and type of housing, and the ease or difficulty in changing the heat conservation characteristics of existing and new structures, would be important determinants of how heating price increases would affect the locational decisions of households. At a somewhat more general level it seems clear that anything which increases the maintenance costs of housing units will tend to reduce demand for housing at any given price or rental rate. Increases in petroleum prices may have a significant effect on the overall cost of operating a housing unit.

At the same time it seems clear that for most major urban areas in Canada other influences, such as population growth, income increases, and price expectations, have more than offset the effects of heating price increases. While it is theoretically possible for increases in heating costs to reduce demand for housing to such an extent that housing prices would fall below replacement cost, there is no evidence that such a phenomenon has occurred in major urban areas in Canada. In situations where replacement costs set an effective lower bound for housing prices, there is little scope for heating costs to have a substantial effect on urban structure, except in so far as the relative demands for different types of housing are affected. In other words, while heating costs may have an effect on the prices of different types of dwellings, one would not expect the effect to be strong enough to influence the equilibrium supply of housing units to any substantial degree.

Although very little research has specifically addressed the question of the effect of petroleum price increases on housing prices, a recent paper by Halvorsen and Pollakowski (1981) has considered this issue. Here the price of housing is considered to be a function of a variety of housing attributes, one of which is the type of fuel used for heating. The authors confine their attention to houses heated by fuel oil and natural gas and consider the extra costs faced by households that heat with fuel oil when the price of fuel oil rises relative to the price of natural gas. They formulate an expression for the loss in consumer surplus which is shown to depend on the percentage difference in the prices of these two fuels. The capitalized difference in expected consumer surplus will then be reflected in the relative prices of the two types of housing.

Because of the fact that their formulation depends on a knowledge of future fuel prices, the authors' expression for changes in housing prices cannot be estimated directly. As an alternative procedure they use a hedonic price equation where house prices are written as a function of housing characteristics, time, and

a set of interactions between time and type of fuel. Both a linear and a semi-log form of the equation were tried, and the semi-log form was found to be preferred by a Box and Cox goodness-of-fit criterion. The data used were collected from a Seattle suburb, and the performance of the hedonic model was judged to be quite good. It was found that when the price of heating oil rose relative to the price of natural gas, prices of fuel-oil-heated houses fell relative to those of natural-gas-heated houses, but with a lag. The differential in house prices was found to be 3.5 per cent for 1974, rising to 16.9 per cent for the first six months of 1975. For a typical oil-heated house in the first half of 1975, valued at $22666, this differential represents a price difference of $4597. The authors admit that this difference is very large when compared with the cost of conversion of fuel oil heating to gas, and they offer as an explanation the uncertainty that surrounded the continued availability of the natural gas option.

It seems unlikely that these results will have much relevance for Canadian urban areas. While it is not difficult to believe that a relative price increase in fuel oil would result in relatively lower prices for houses heated by fuel oil if conversion is not possible, there is no prospect of a shortage of natural gas in Canada, and current government subsidies for conversions have resulted in relatively modest conversion costs. Furthermore, as was argued at the beginning of this section, fuel costs seem unlikely to have a large enough influence on demand to affect urban structure significantly.

One conclusion that can be reached from this analysis is that higher fuel oil prices (relative to natural gas prices or electrical rates) are likely to result in a significant amount of substitution to cheaper heating systems. The natural tendency for households to switch to cheaper fuels will be reinforced by the real or expected effect that the heating system will have on the price of the residence. One would also expect other forms of conservation, such as installing more insulation, to be encouraged by such relative price changes. All such changes will temper the effects of increases in petroleum prices.

A second issue associated with the question of the effects, through the housing market, of petroleum price increases on urban structure is the supply response of housing to house price increases. Even if petroleum price increases do not have a significant direct effect on house prices, there will be some pressure on housing prices from the increase in transportation costs, the amount of the pressure depending, as was discussed in Chapter 3, on the relative importance of substitution and relocation. Whatever the price effect, however, it is of interest to know the extent to which this pressure will generate a supply response. Obviously the price elasticity of supply is relevant to the question of how urban structure will be affected by house price increases.

Among the many models that have been developed to examine the housing market, perhaps the most comprehensive and ambitious is that of Bradbury, Engle, Irvine, and Rothenberg (1977). The housing model in this study is part of a more general model, which consists of three submodels: a macro model determining overall economic activity, a model determining household supply and demand, and a model to determine the spatial distribution of business activity. The model was designed for policy analysis in the Boston metropolitan area. In this paper the authors report on the household location submodel, of which the supply side is of particular interest for the analysis here.

In their supply analysis Bradbury et al. focus on the number and type of housing units made available to households by zone in the metropolitan area. Sources of supply are the construction of new units and conversion of space from other or different housing uses. Their two sources of supply are assumed to be determined by different variables in the model. New construction is considered to be a function of zoning regulations, sewer availability, and proportion of the area vacant. It is of interest to note that housing prices were not considered to be a determinant of new construction. For the conversion and demolition supply equation, the dependent variables were housing prices, vacancy rates, the number of old units, the number of deteriorating units, zoning restrictions, and the existence of public housing. The price variable was significant and negative for conversion of a single-family dwelling, indicating that as housing prices rise, single-family houses are demolished. The price variable for multifamily units and apartments was positive but not statistically significant. This study, then, provides only very weak support for the proposition that higher housing prices will generate a positive supply response.

These results have important implications for much of the study and are particularly relevant for the simulations carried out in Chapter 6. It has been argued that the effect of gasoline price increases on urban structure, on the assumption that there will be some tendency for households to move towards the CBD, will depend on the extent to which the existing housing stock can adjust to accommodate such shifts. In Chapter 2 the literature reviewed suggested that there is significant intertia in the housing stock, the conclusion being that changes in gasoline prices would not be expected to result in major structural change in the medium run. The evidence on the housing market presented here clearly supports this hypothesis.

In Chapter 6 two kinds of simulations were performed, one assuming perfect flexibility in the housing stock and the second assuming a fixed stock where the principal form of adjustment was in rents and housing prices. The empirical literature suggests that the version with the housing stock fixed is likely to be the

most realistic, perhaps even in the long run. Again, then, one is led to the conclusion that although rents and housing prices may change significantly when gasoline prices increase, the physical structure of urban areas is unlikely to undergo significant changes.

CONCLUSIONS

The empirical work that has been surveyed has several implications for this study. The literature on the demand for gasoline very clearly suggests that while the long-run price elasticity of demand may be close to unity, the reduction in gasoline consumption will come mainly from the use of more efficient automobiles, not primarily from less miles driven. The comprehensive study by Sweeney (1981), for example, argues that the long-run price elasticity of gasoline is –0.78 but that, of this, only –0.06 would be attributed to a reduction in miles driven, with –0.72 attributable to the use of more efficient automobiles. These results strongly indicate that when faced with the alternatives of moving or substituting alternative modes of travel (such as more efficient cars), the substitution alternative will predominate. From this evidence one would be surprised to find any significant increase in demand for housing near the CBD associated with increases in gasoline prices.

The investigations of the demand for automobiles indicated that disposable income is the single most important determinant of automobile ownership. If predictions that per capita income will continue to rise are correct, one would expect to observe in the future an increase in the proportion of households that own automobiles. Increased automobile ownership would, in turn, be expected to continue the trend towards suburbanization that has been such an important phenomenon of the past fifty years. All studies find that the gasoline elasticities of auto purchases are small, suggesting that higher gasoline prices will not prove to be a significant deterrent to automobile sales.

The literature on the demand for urban transit supports the suggestion of Chapter 3 that the most significant variable determining transit use will be the time cost of travel. The empirical evidence suggests that transit ridership is not very responsive to the fare, and that for transit travel the elasticities with respect to time are approximately three times as high as the similar elasticities for car travel time. In addition, significant elasticities for transit service were found for walk time and waiting time. McFadden (1973) did find that bus travel was responsive to car costs.

The literature on housing suggests that the supply of housing near the CBD is not very responsive to housing price, although increases in housing prices do have a significant positive effect on the demolition of single family units. A study

by Halvorsen and Pollakowski (1981) shows that increases in fuel oil prices relative to the price of natural gas will have a significant negative effect on the price of houses heated by fuel oil. This fact is unlikely to have much significance for housing prices in Canadian urban areas where natural gas is plentiful and where conversion is subsidized by the government. This study does suggest, however, that there will be significant incentive to improve the heating characteristics of both old and new houses.

8
Urban structure in Canada

INTRODUCTION

Much of this study thus far has been based on the analysis of stylized models of urban areas. Abstracting from the full complexities of reality in order to address specific issues is standard economic (and scientific) methodology, which requires no apology. Furthermore, the types of models used in this study have been given considerable empirical support in the literature (e.g., see Mills, 1972). None the less, it is naturally of interest to examine the details of actual urban structure and its relationship to petroleum costs in Canada. It is the purpose of this chapter to provide a brief survey of what is known about urban structure in Canada, concentrating, of course, on aspects relevant to energy costs. The emphasis will be on aspects related to urban travel. The approach taken here is that of an economist, not a geographer. Thus, it will be clear that this survey is by no means a definitive geographic summary of energy cost-related aspects of urban structure. Rather, the intention is to give a stylized picture of the critical economic parameters.

Of Canadian cities there will be an emphasis here on Ontario cities, particularly Toronto, which has been studied more thoroughly than any other Canadian city. This focus has drawbacks, since in many ways Toronto is atypical of Canadian cities, being much larger in size and in population, more diffuse, and perhaps more multinucleated than the 'typical' Canadian city. On the other hand, a significant part of the 'action' in terms of urban growth by the end of the century in Ontario and in Canada will take place in Toronto, so that the disproportionate focus on Toronto is partially justified. (Table 11, summarizing projected growth rates of Canadian CMAs, shows that population projections suggest that 26 per cent of the growth in number of households occurring in the twenty-two largest Canadian metropolitan areas between 1975 and 2000 will

TABLE 11

CMA households in 1975, 1985, 2000

	Number of estimated households, 000s		
CMA	1975	1985	2000
Toronto	925	1 500	1 830
Montreal	925	1 146	1 340
Vancouver	412	667	950
Ottawa-Hull	222	325	476
Winnipeg	198	236	275
Edmonton	148	296	430
Hamilton	175	225	287
Quebec	150	211	249
Calgary	150	290	415
St Catharines	111	127	168
London	104	150	190
Windsor	86	110	163
Kitchener	84	129	180
Victoria	81	94	133
Halifax	76	85	102
Regina	48	60	71
Sudbury	46	62	102
Saskatoon	43	60	70
Chicoutimi	41	50	59
St John's	36	51	72
Thunder Bay	35	50	57
St John	34	36	42
TOTAL	4 160	5 960	7 660

SOURCE: Transport Canada (1979)

occur in Toronto.) Finally, the average (moderate-sized) Canadian city conforms much more closely than does Toronto to the simple journey-to-work model discussed throughout this study. Therefore one can feel more comfortable about the application of that analysis to those cities, whereas Toronto, being a different but important special case, deserves closer scrutiny.

PROFILE OF CANADIAN CITIES

A great deal of information related to urban travel in Canadian cities is summarized in *The Future of the Automobile in Canada* (Transport Canada, 1979). Much of that information is reproduced in Tables 12–17. In addition, Statistics Canada (1979) has developed data on journey-to-work in Canada, some of which is provided in Tables 18 and 19.

TABLE 12

Estimated allocation of auto mileage between urban and rural areas 1975

Area of origin	Internal urban auto mileage (billions)	Other auto mileage (rural and intercity) (billions)	Total
22 CMAS	35	12	47
Urban areas 25 000–100 000 population	6	2	8
Urban areas 1 000–25 000 population	9	3	12
Rural areas	1	19	20
TOTAL	51	36	87

SOURCE: Transport Canada (1979)

In Table 12 automobile mileage in Canada is broken down between urban and rural areas. We see that over 40 per cent of the automobile mileage in Canada is internal to the twenty-two large CMAs. Thus urban automobile commuter travel is clearly a very important component of total automobile travel and thus of total gasoline consumption in Canada. Data on energy consumption will be presented later in this chapter.

The data presented in Tables 13–15 support the prediction of the journey-to-work model that average distance from the CBD will increase with population (the simple correlation coefficient between number of households and average distance from the CBD is 0.74). Of course, of more interest is how average commuting trip length varies across cities. These data are provided in the last column of Table 15. Not surprisingly, average commuting trip length is also positively related to population, although this relationship is more variable than the relationship between population and average distance to the CBD, principally because topographic features differ significantly across cities (the simple correlation coefficient is 0.69). The positive relationship between average commuting trip length and population is also borne out by the results of the study by Hutchinson and Smith (1980). What is the import of this positive relationship? The journey-to-work model assumes that all employment is located in the CBD. Of course, in any 'real' city employment is diffused throughout the city. One possibility for urban structure is for cities to be multinucleated, locating employment in such a way that any moderate-to-large size city would be essentially composed of a number of small, largely independent, city-like configurations. In

TABLE 13

Distribution of commuters by distance to work, Canada and provinces, 1975

Province	Total commuters (000s)	Distance to work in miles					
		Less than 1	1–2	3–5	6–12	13–22	23 and more
Canada	8 002	1 013	1 412	2 015	1 654	1 101	662
Newfoundland	138	25	34	31	18	12	13
Prince Edward Island	32	5	8	6	5	n/a	n/a
Nova Scotia	248	39	52	61	35	30	28
New Brunswick	201	32	41	40	36	26	24
Quebec	2 065	278	361	482	436	306	158
Ontario	3 227	364	531	817	696	487	279
Manitoba	322	51	60	96	69	27	13
Saskatchewan	235	50	59	64	25	19	13
Alberta	615	82	109	185	114	52	57
British Columbia	917	86	156	233	221	138	71

SOURCE: Statistics Canada (1979)

TABLE 14

CMA households and auto mileage estimates, 1975

CMA	Estimated households (000s)	Auto miles to work (millions)	Total internal CMA auto mileage (millions)
Toronto	925	4 850	9 420
Montreal	925	4 420	8 590
Vancouver	412	1 940	3 770
Ottawa-Hull	222	870	1 700
Winnipeg	198	680	1 320
Edmonton	148	680	1 320
Hamilton	175	850	1 650
Quebec	150	480	930
Calgary	150	510	990
St Catharines	111	410	800
London	104	370	720
Windsor	86	290	570
Kitchener	84	270	520
Victoria	81	250	490
Halifax	76	200	380
Regina	48	140	270
Sudbury	46	190	370
Saskatoon	43	120	240
Chicoutimi	41	120	240
St John's	36	120	240
Thunder Bay	35	100	190
St John	34	140	270
TOTAL	4 160	18 000	35 000

SOURCE: Transport Canada (1979)

such a situation average commuting trip length might not be positively related to population and the journey-to-work model would be a poor representation of an *aggregate* city (although not, perhaps, of the smaller city-like configurations). However, the data show that employment becomes more distant relative to place of residence as city population grows. Therefore, although the journey-to-work model is by no means a perfect stylized version of cities (particularly large cities), as a crude stylized picture and particularly as a description of how gasoline price increases might be expected to affect urban structure, it is probably satisfactory. An additional piece of evidence in support of the journey-to-work model is that in most cities the CBD is an important area of employment destination for all major residential areas, a feature that will be discussed in more detail for Toronto below.

TABLE 15

Estimated average straight-line distances of dwellings from CMA centres and actual and estimated auto trip lengths to work, 1975

CMA	Estimated households (000s)	Estimated population (000s)	Estimated average straight-line distance of dwellings from CMA centre (miles)	Actual and estimated average auto trip length to work, 1975 (miles)
Toronto	925	2 750	5.8	10.9*
Montreal	925	2 800	4.9	9.9*
Vancouver	412	1 150	5.5	9.8*
Ottawa-Hull	222	640	3.7	8.1*
Winnipeg	198	580	2.9	7.0*
Edmonton	178	560	3.3	7.8*
Hamilton	175	530	3.7	10.2*
Quebec	150	510	3.0	6.6*
Calgary	150	480	2.9	7.0*
St Catharines	111	310	3.4	7.6†
London	104	300	3.4	7.6†
Windsor	86	270	3.0	7.1†
Kitchener	84	240	2.7	6.6†
Victoria	81	210	2.5	6.4†
Halifax	76	220	2.6	5.7*
Regina	48	150	2.0	5.7†
Sudbury	46	160	4.4	9.0†
Saskatoon	43	130	1.8	5.4†
Chicoutimi	41	140	2.2	6.0†
St John's	36	130	3.1	7.1†
Thunder Bay	35	110	2.2	6.0†
St John	34	120	4.0	8.5†
TOTAL	4 160	12 500	4.4‡	8.9‡

SOURCE: Transport Canada (1979)
* Actual average trip length to work
† Estimated average trip length to work
‡ Weighted average in terms of households

It was argued in Chapter 5 that gasoline costs are not the only important component of travel costs. In particular, commuting takes time that residents could use for other purposes; thus commuting time is an important component of travel costs. Table 16 provides some evidence on how commuting time varies across some of the major CMAs. The data presented there also give some rough

TABLE 16

CMA auto trip lengths and speeds to work, 1975

CMA	Average work trip length (miles)	Average work trip time (minutes)	Average work trip speed (mph)
Toronto	10.9	23.0	28
Montreal	9.9	22.0	27
Vancouver	9.8	21.5	27
Ottawa-Hull	8.1	18.5	26
Winnipeg	7.0	19.5	21
Edmonton	7.8	20.0	23
Hamilton	10.2	22.0	28
Quebec	6.6	15.5	25
Calgary	7.0	19.0	22
Halifax	5.7	17.5	19
Weighted averages	9.0	19.5	27

SOURCE: Transport Canada (1979)

indication of commuting travel congestion across cities (proxied by travel speed). Table 16 gives some indication of the importance of topographic features and urban travel infrastructure as a determinant of travel time. Although there is a strong relationship between population and average work trip length, the relationship between population and travel time is much more ambiguous.

Another important issue to address is the importance of public transit in urban commuting. Naturally, the relationship between gasoline prices and automobile travel costs is stronger than that between gasoline prices and public transit, particularly in areas in which electricity is an important component of energy use (such as subways). There is a close association between population and percentage of commuting trips made by public transit, as indicated by Table 17.

A more complete breakdown of the principal means of travel by commuters on a provincial basis is given in Table 18.

Naturally, commuting travel is only one component of total urban travel. Urban dwellers also travel to shop, for recreation, etc. Table 19 provides some very interesting data estimating automobile mileage used for different trip purposes. Roughly speaking, suburban residents use a higher percentage of their total travel for non-commuting purposes than central city residents do. This fact is of importance in interpreting the simple models of the preceding chapters in that, on average, residents living further from the CBD engage in more automobile travel than central city residents do. If, for example, suburban residents were located much closer to non-employment-related travel destinations than central city residents were, the predictions of the journey-to-work

TABLE 17

Work trip transit usage in the nine largest CMAs, 1975

CMA	1975 population (000s)	Per cent of trips to work made by transit, 1975	Per cent of commuters to which transit 'available'
Toronto	2 750	35	82
Montreal	2 800	32	81
Vancouver	1 150	20	73
Ottawa-Hull	640	31	74
Winnipeg	580	27	85
Edmonton	560	22	64
Hamilton	530	20	70
Quebec	510	16	66
Calgary	480	20	80
All CMAs	12 500	26	77.5

SOURCE: Transport Canada (1979)

TABLE 18

Principal means of travel by commuters, Canada and provinces, 1975 (100 per cent base)

Province	Total	Driving alone	Driving with passenger(s)	Riding as passenger	Public trans-portation	Walking
Canada	75	53	9	13	15	8
Newfoundland	81	48	12	21	4	11
Prince Edward Island	88	56	n/a	19	n/a	n/a
Nova Scotia	81	49	13	20	6	10
New Brunswick	85	49	13	23	2	10
Quebec	72	47	9	16	16	9
Ontario	73	53	8	12	17	8
Manitoba	72	51	9	12	18	8
Saskatchewan	84	60	10	14	6	9
Alberta	78	59	10	9	14	7
British Columbia	81	61	9	10	12	6

SOURCE: Statistics Canada (1979)

model would be suspect. However, the data on non-employment-related travel suggest that the journey-to-work model's relative predictions about central city and suburban values and densities are strengthened.

ENERGY USE IN ONTARIO

In this section evidence on energy use in Ontario will be presented and examined; there are a number of issues here to be addressed. In this study the focus

TABLE 19

Estimated average annual automobile mileage per household by area of origin and trip purpose from automobile survey,* 1976 (percentages in parentheses)

Area of origin	Commuting	Commercial	Personal	Shopping	Business	Daily recreation	Weekend	Vacation	Total
CMA core	4 999	764	217	484	717	1 360	1 311	1 262	11 114
	(47)	(7)	(2)	(5)	(7)	(13)	(12)	(12)	(100)
CMA fringe	4 500	989	410	851	1 182	1 845	1 666	1 158	12 100
	(36)	(8)	(3)	(7)	(9)	(15)	(13)	(9)	(100)
Small city	3 219	1 888	1 212	1 195	2 044	1 858	1 077	937	13 430
	(24)	(14)	(9)	(9)	(15)	(14)	(8)	(7)	(100)
Rural	6 378	949	444	1 154	2 309	2 210	819	1 520	15 783
	(40)	(6)	(3)	(7)	(15)	(14)	(5)	(10)	(100)

SOURCE: Transport Canada (1979)
* Based on 717 interviews

TABLE 20

Energy consumption profile for Ontario, 1979

Sector	Per cent of total energy
Residential	41
Industrial	25
Transportation	21
Commercial	11
Institutional	2

SOURCE: Ministry of Energy (1981)

TABLE 21

Energy consumption profile for Borough of York (Toronto), 1975

Sector	Per cent of total energy
Industrial	39
Transportation	28
Residential	21
Commercial	10
Institutional	2

SOURCE: Ministry of Energy (1981)

has been mainly on the relationship between travel costs (gasoline) and urban structure. Of course travel is not the only important user of energy. Tables 20–23 summarize information on energy consumption by sector, oil consumption by sector, and energy consumption by mode of travel.

Notice the difference, in Tables 20 and 21, in the relative importance of energy use among sectors between the aggregate Ontario data and the data for York. Urban areas such as York are more industry-intensive than Ontario as a whole is.

The data presented in Tables 20 and 21 represent total energy consumption. However, transportation is predominantly a petroleum-based energy user. Therefore the percentage of oil used in transportation is considerably higher than the percentage of total energy used in transportation. Data on oil consumption profiles are presented in Nitkin (1980) and are summarized in Table 22.

Nitkin (1980) also presents data on energy consumption (predominately oil) by various forms of transportation. This information is summarized in Table 22.

From Tables 22 and 23 it can be seen that urban automobile passenger travel accounts for approximately 16 per cent of the petroleum used in Ontario. Therefore, for example, if long-run changes in urban structure alone reduced

TABLE 22

Oil consumption in Ontario by sector, 1974

Sector	Per cent of total energy
Transportation	50.1
Residential	22
Industrial	20.3
Commercial	7.6

SOURCE: Nitkin (1980)

urban travel sufficiently to reduce petroleum usage in urban passenger travel by 10 per cent, other things being equal, the reduction in *total* petroleum consumption in Ontario would be less than 2 per cent. However, it would take a considerable length of time for urban structure to adjust sufficiently, other things being equal, to produce a reduction in urban passenger travel by 10 per cent. On the other hand, other means of substituting in face of gasoline price increases can occur much more quickly. For example, the U.S. government's new car fuel economy standards, if met, mean that the average new automobile produced in 1985 will have an mpg in excess of 50 per cent above the fuel economy of the average 1976 automobile (Frankena, 1980). Of course it will probably take considerably longer for the fleet of existing cars to achieve such a marked increase in fuel economy. Another example of other forms of substitution is increased insulation of existing housing, with the consequent energy conservation benefits. Thus it seems clear that changes in urban structure per se are not likely to have a significant impact on petroleum use in the short run and that other, quicker forms of substitution will certainly predominate in importance. Urban structure is long lived, however, so it is important that decisions about current changes in urban structure (e.g., new development, energy efficiency of new construction) are made in a climate in which the energy cost effects of such decisions are fully recognized.

Figure 10 is a map on which are plotted residential densities by census tract. (The figure is taken from Metropolitan Toronto Planning Board [MTPB, 1974].) Although Figure 10 is clearly not a map of a simple journey-to-work model city, the general tendency for density to decrease with distance from the CBD in Toronto is certainly not a repudiation of the journey-to-work framework. As would be expected, densities are generally higher along main commuter corridors (e.g., the subway), reflecting the fact that travel time is an important component of travel costs.

Data on how population has changed over time in various regions are provided in MTPB (1974). Some are reproduced in Figures 11 and 12. The data

TABLE 23

Energy consumption by mode of travel in Ontario

Sector and mode	Per cent of transportation energy		
Intercity passenger			
Automobile	16.8		
Air	1.8		
Bus	0.2		
Rail	0.6		
Subtotal		19.4	
Urban passenger			
Automobile	31.7		
Electric transit	0.1		
Bus transit	0.5		
GO transit	0.1		
Taxi	0.7		
Subtotal		33.1	
TOTAL PASSENGER			52.5
Intercity freight			
Rail	4.2		
Marine	4.3		
Truck	16.1		
Gas and oil pipeline	4.5		
Subtotal		29.1	
Urban truck			
Freight	5.3		
Non-freight	7.3		
Subtotal		12.6	
TOTAL FREIGHT AND TRUCK			41.7
Other			5.8

SOURCE: Nitkin (1980)

presented in Figures 11 and 12 do indicate that Toronto is becoming increasingly suburbanized, as would be expected in a fast-growing city. This tendency to suburbanization of course is strengthened by the height restrictions imposed on development in Toronto.

Evidence on employment concentrations is also provided in MTBP (1974), some of which is summarized in Figure 13. For example, Figure 13 shows that the core area of Toronto is the single largest area of employment concentration.

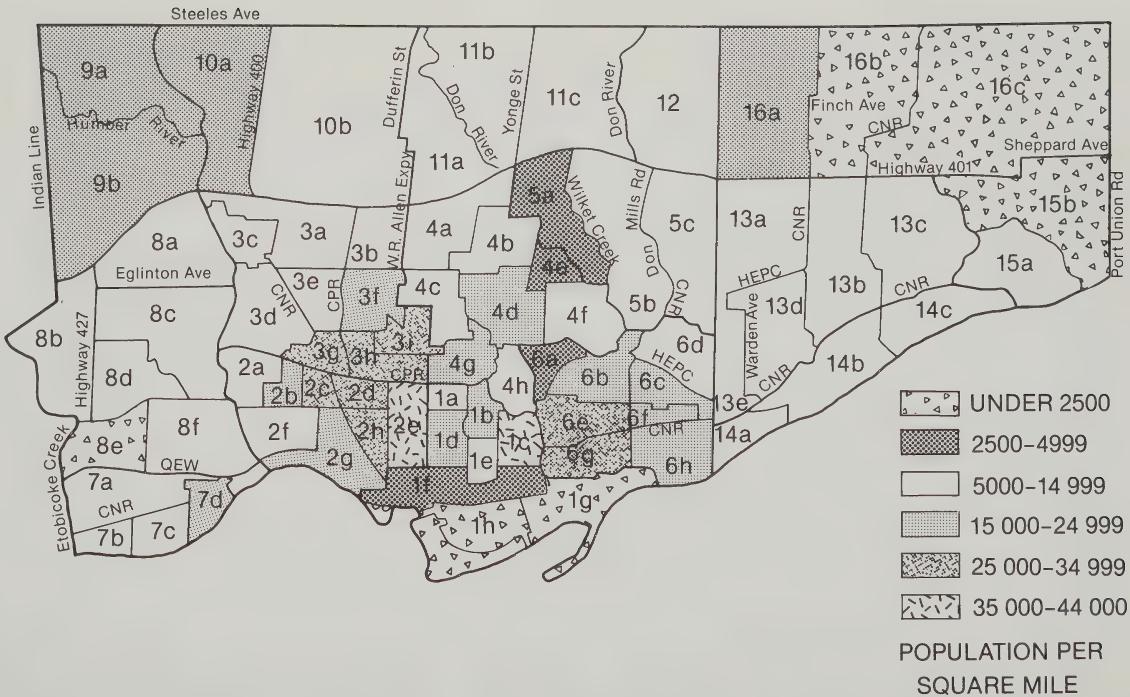


Figure 10
Gross population densities, metropolitan Toronto minor planning districts, 1971
(Source: MTPB, 1974)

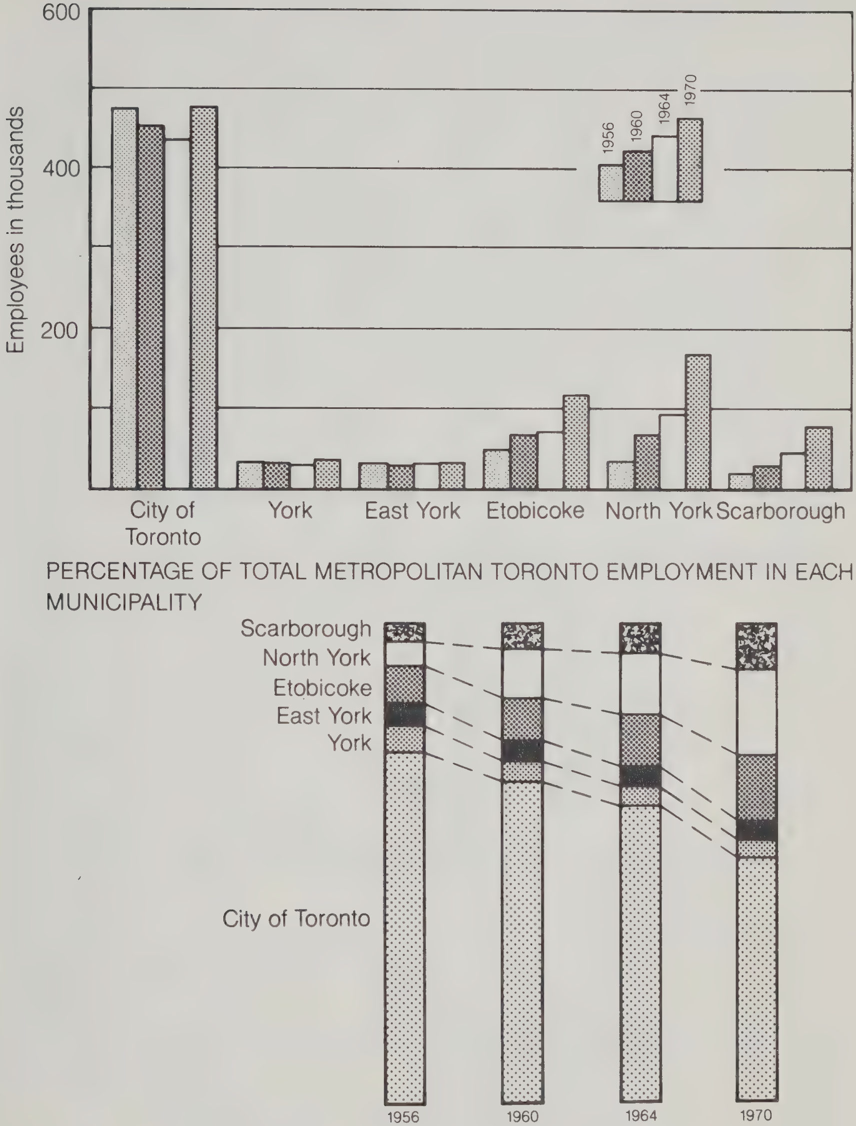


Figure 11
Employment distribution by place of work, metropolitan Toronto by municipalities, 1956, 1960, 1964, 1970 (Source: MTPB, 1974)

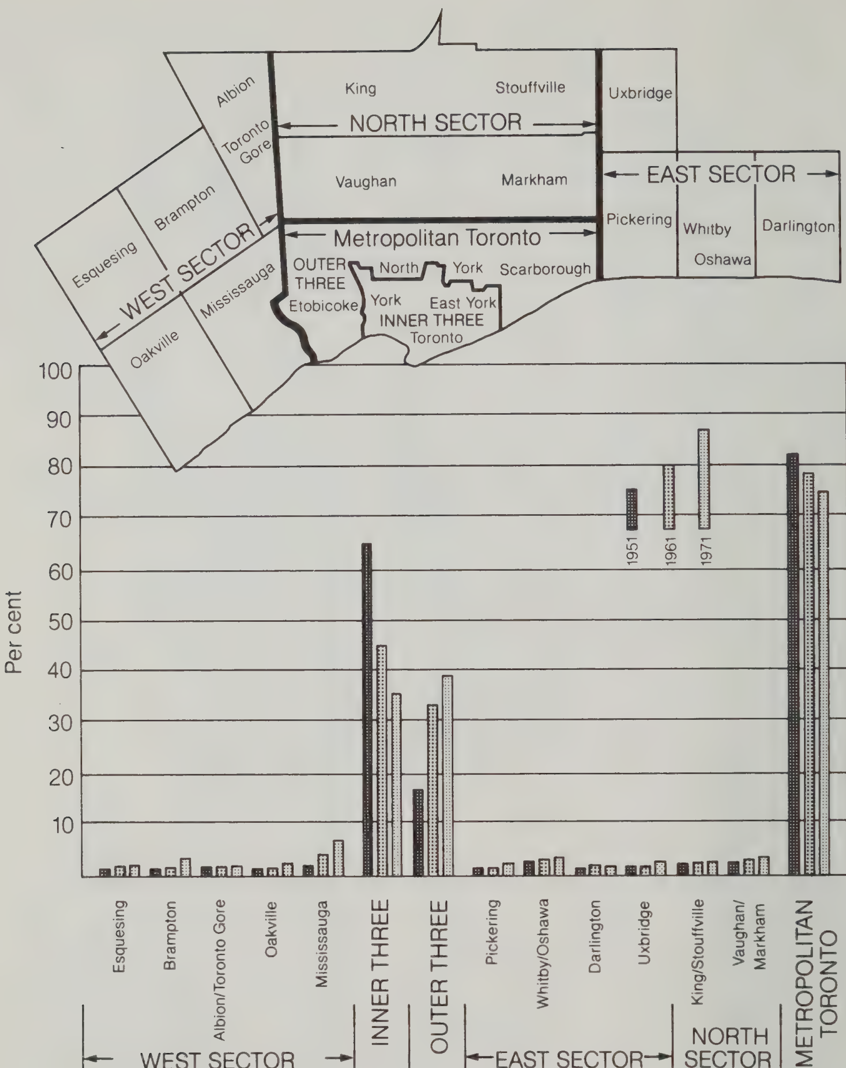


Figure 12
Population, percentage of regional total within each sub-area, 1951, 1961, 1971 (Source: MTPB, 1974)

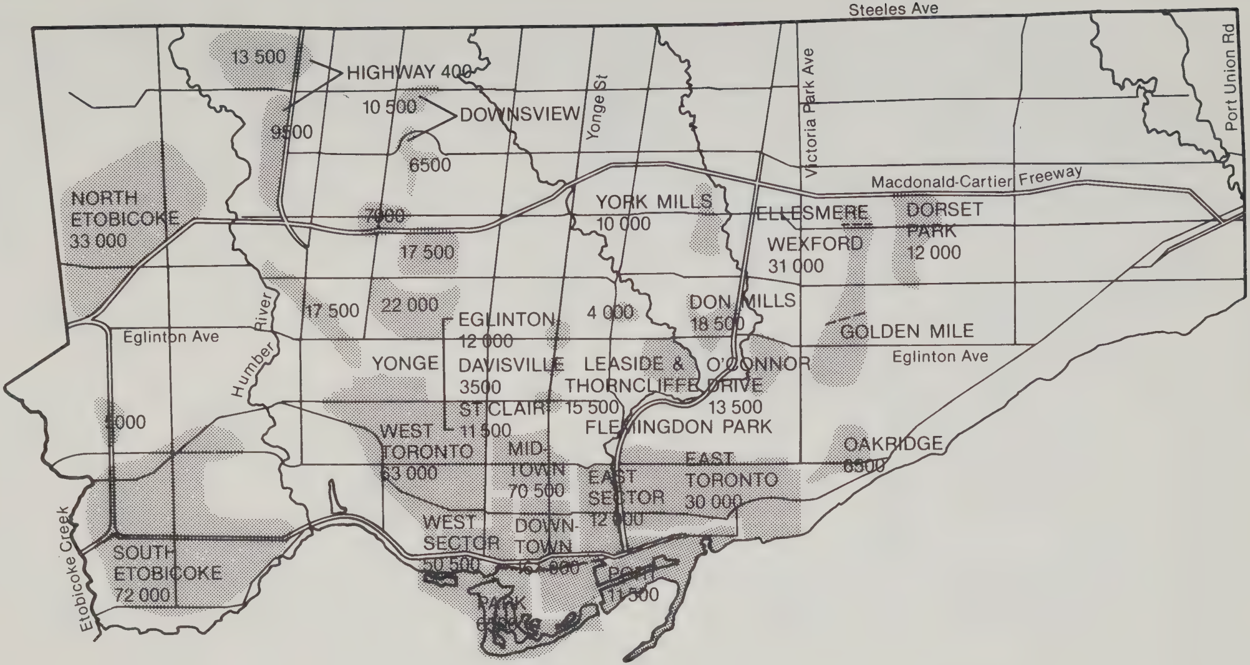
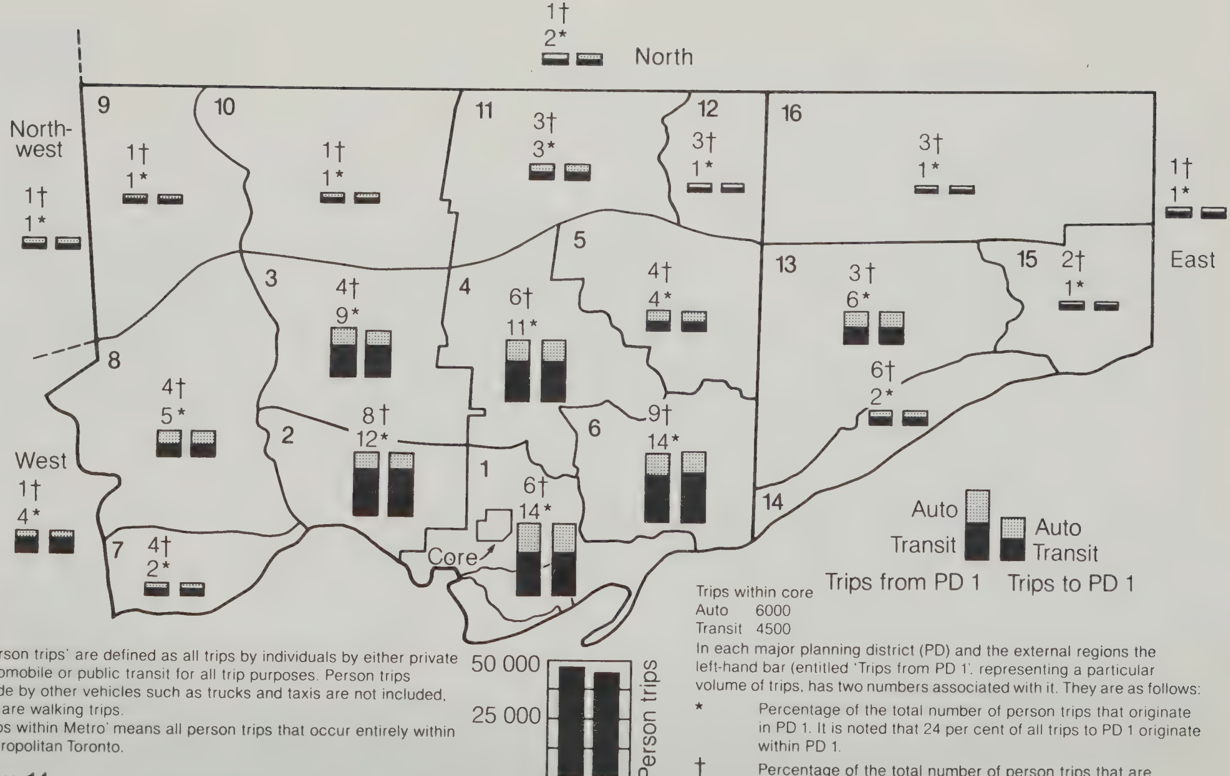


Figure 13
Employment concentrations, by place of work, metropolitan Toronto, 1970
(Source: MTPB, 1974)



Trips within core
Auto 6000
Transit 4500

In each major planning district (PD) and the external regions the left-hand bar (entitled 'Trips from PD 1', representing a particular volume of trips, has two numbers associated with it. They are as follows:

* Percentage of the total number of person trips that originate in PD 1. It is noted that 24 per cent of all trips to PD 1 originate within PD 1.

† Percentage of the total number of person trips that are destined to this particular PD or region.

NOTE:
1. 'Person trips' are defined as all trips by individuals by either private automobile or public transit for all trip purposes. Person trips made by other vehicles such as trucks and taxis are not included, nor are walking trips.
2. 'Trips within Metro' means all person trips that occur entirely within metropolitan Toronto.

Figure 14
Auto and transit person trips to and from the core in twenty-four hours, 1971
(Source: MTPB, 1974)

TABLE 24

Employment by place of work, percentages of municipal residential populations, 1956, 1970 (from MPTB, 1974)

	1956					1970				
	Population		Employment,	Ratio emp./pop.		Population		Employment,	Ratio emp./pop.	
Municipalities	Total	Age 20–64	total	Total	Age 20–64	Total	Age 20–64	total	Total	Age 20–64
City of Toronto	695 800	440 700	465 600	66.9	105.7	709 710	425 760	469 200	66.1	110.2
York	127 100	79 300	32 400	25.5	40.9	146 990	87 235	37 500	25.5	43.0
East York	86 200	53 600	30 900	35.9	57.7	102 920	64 270	32 500	31.6	50.6
Inner Three	909 100	573 600	528 900	58.2	92.2	959 620	577 265	539 200	56.2	93.4
Etobicoke	139 100	83 300	44 800	32.2	53.8	279 180	158 395	119 400	42.8	75.4
North York	170 100	98 700	36 100	21.2	36.6	483 280	276 026	176 300	36.5	63.9
Scarborough	139 700	79 300	20 400	14.6	25.7	323 120	175 000	85 500	26.5	48.9
Outer Three	448 900	261 300	101 300	22.6	38.8	1 085 530	609 421	381 200	35.1	62.6
METROPOLITAN TORONTO	1 358 000	834 900	630 200	46.4	75.5	2 045 150	1 186 680	920 400	45.0	77.6

SOURCES: Population: 1956–Census of Canada; 1970–interpolated from Censuses for 1966 and 1971. Employment: MTPB Surveys,

Of more interest from the point of view of the journey-to-work model is the relationship between location of dwelling and location of employment. Although employment is diffused throughout Metropolitan Toronto and the more distant suburbs, the city core is an important location of employment for commuters throughout the area. This is shown in Figure 14 (MTPB, 1974), which gives some indication of commuter trips to the core, and in Table 24 (MTPB, 1974), which provides data on employment vs population in the major regions.

It is clear that Toronto is not a monocentric city. However, the city core is an important source of employment for virtually every region of residential location. Naturally the impact of gasoline price increases on urban structure and residential real estate values at a particular location could not be accurately predicted simply from the knowledge of the commuting travel distance from the core. Other major employment locations would have to be taken into account, as would the location of other important trip-generating destinations (e.g., shopping). However, the predictions of the simple journey-to-work model are not without value. It would be expected that the short-run impact of unanticipated increases in gasoline prices would be to raise values of residential real estate located near (within commuting distance of) major employment locations. Similarly, the long-run effects would be expected to be denser clustering of residential densities around major employment centres with corresponding increased densities and property values proximate to these centres.

9
Policy implications and conclusions

INTRODUCTION

The goals of this chapter are very modest, and the reader hoping for solutions to all the problems facing urban areas will be disappointed. Indeed, even for the specific issue of the effect of increasing gasoline prices on urban areas no firm policy recommendations of a general nature can be suggested. The reasons for the inability to formulate specific recommendations are twofold. First, cities, suburbs, industries, and individuals differ to such an extent that even if a set of policy recommendations could be formulated for Toronto, say, they might be quite inappropriate for Vancouver or Calgary. Second, throughout the study it has been argued that several different responses to higher petroleum prices are possible, and the policy implications of these responses are often quite different. There is no evidence that a single response will be expected to dominate, and indeed some complex combinations of the various reactions would be the expected result.

To consider a specific example of the kind of difficulty that can be encountered, suppose an urban government is considering widening a major thoroughfare to the CBD. How would anticipated increases in gasoline prices be expected to influence such a decision? If it is felt that there will be a significant shift in population towards the CBD, as would be predicted by the simple version of the journey-to-work model, then there would be a reduction in miles driven per capita, and additional access to the CBD may not be required, making the widening of the existing expressway unnecessary. On the other hand, suppose the principal reaction by households is to change to more efficient modes of transportation, either by switching to more efficient cars or by taking a bus or rapid transit to work. In this case there would be little change in residential density near the CBD, and with a growing population additional access to the

CBD may be required. It is clear that decisions about whether new or improved expressways will be required depend on the reactions of households to gasoline price increases. These reactions cannot be determined on the basis of theoretical analysis, and at this point there are insufficient data available to reach definitive conclusions on empirical grounds.

The example given above considered only the reaction of households to gasoline price increases. As has already been suggested, there may also be incentives for firms to relocate when petroleum prices rise. In one sense the determination of whether a firm will move is simpler, because in general one would expect a firm to relocate if doing so would increase profits. But while such a general statement is correct, it is not of much assistance, since ways in which costs and revenues are affected by petroleum price increases will differ widely. The question of whether a specific firm would find it profitable to relocate would need to be answered on an individual basis, and would depend on factors such as the nature of the product and the inputs, whether markets were local or 'foreign,' what the principal mode of transport is, and whether an adequate labour force can be found in the new location.

Finally, note that there are still other factors that would have to be taken into account. Heating costs may be an important component of household decision-making and will differ significantly both across and among cities. Travel for purposes of shopping and recreation may be a significant determinant of a household's location and would be expected to vary among households and locations. Taking all these factors into account, it thus seems clear that no general statement will be possible concerning the effects of petroleum price increases on the policy-making process.

But if no general statements are possible, does this mean that no policy recommendations of any kind can be derived from the analysis? Fortunately not, for the analysis presented in the preceding chapters can be useful to policy-makers in at least two distinct ways: the analysis should prove useful in the identification of those aspects of *specific* situations that will allow a judgment on what policy should be pursued, and the analysis has defined broad extremes between which the actual outcome will almost certainly lie. The identification of the policies appropriate for the extreme cases will provide important information about the range that policy will take and will also serve to indicate the extent to which inappropriate policies could be harmful.

As to the identification of the important elements for specific situations, very little more can be suggested, for by the very nature of the approach each issue must be analysed on the basis of the features of the problem that are most relevant. The types of policies that would be considered appropriate for the polar cases we have identified can be discussed, and this will be done in the third

section. Before that set of questions is taken up, however, the following section will attempt to provide a background to such a discussion by identifying situations in which government intervention could be seen as appropriate.

REASONS FOR PUBLIC INTERVENTION

In order to understand more clearly the range of policy options open to urban governments, or governments who legislate on urban issues, this section will attempt to identify, in very broad terms, the kinds of market failure that could exist in urban areas and therefore justify the intervention of local or provincial governments. The focus, of course, is on market failures that can specifically be identified with increases in petroleum prices, since a general discussion of urban policy problems is well outside the scope of this study.

In general, the kinds of circumstances that would justify government intervention would include the presence of externalities, the provision of public goods, and the failure of the market to provide the appropriate social discount rate for capital expenditure decisions. Gasoline price increases could well generate appeals for public action on all these grounds. For example, the single most important source of diseconomies in an urban area is undoubtedly the automobile, and should oil price increases result in a much denser city with less travel, many of the policies that facilitated the extensive use of cars for commuting could be curtailed, or at least not expanded at the rate seen appropriate for lower gasoline prices. Less money could be allocated to road maintenance and improvement and improvements made in public transportation. On the other hand, should substitution and technological improvement outweigh journey-to-work effects, such policies may not be appropriate, at least as far as the effect of rising petroleum prices is concerned.

Should cities become more dense, public goods such as parks and schools will be demanded in the downtown area, and expenditures for such items could be shifted from the suburbs. The opposite shift would be required if urban sprawl is encouraged by substitution and technological change.

Another area in which public action could be recommended would be the prevention of inappropriate public expenditures that could result from the timing of petroleum price increases. Suppose, for example, that it is known that gasoline prices will rise some significant amount in the future. Decisions on public projects such as the location of schools and parks and whether new expressways should be started depend very much on how it is felt such future price changes are going to affect the structure of urban areas. Whether zoning regulations should encourage or discourage high density construction in the city centre will depend on the reaction of households and industry to the prospect of future price changes.

One possible policy option is to move petroleum prices to their future levels as quickly as possible by increasing excise taxes and allowing the market to adjust, thereby removing the uncertainty. Such a policy would seem quite feasible at the provincial levels but more difficult and perhaps impractical for lower levels of government. Indeed at the present time the combination of Ontario and federal gasoline taxes has succeeded in producing gasoline prices in Ontario not much different from those in the United States, even though petroleum prices are only at about 50 per cent of the U.S. price. Perhaps most of the adjustments to higher gasoline prices in Ontario urban areas have already begun, although continuation of this process clearly depends on whether or not the federal and provincial governments are prepared to reduce the excise tax as the price of petroleum continues to rise.

There may also, of course, be popular policy prescriptions that cannot be supported by market failure arguments. Rent control is one example of a policy that could be particularly harmful in the face of petroleum price increases. Although rent controls are difficult to justify under any circumstances, in this situation they may significantly frustrate any tendency for the market to produce an equilibrium. In Chapter 6 a good deal of attention was paid to the effect that increases in the average cost of commuting would have on urban structure, in both the short and long run. As will be recalled, the short-run effects on rents and the longer-run effects on density and city size were very significant. All such adjustments, however, could be completely frustrated by a rent control system that prevents market prices from being realized. Recall that long-run changes would require a significant amount of demolition and renovation, and the incentive for such activity would be removed if rents are not allowed to respond to market pressure.

There are several consequences of not permitting such adjustments. First, households will not be able to adjust to the new situation in a fashion that would maximize their individual utilities, and thus they will, in general, be worse off. Note that even though they would be paying higher rents, they would be better off because of the reduction in travel costs. Were this not the case, then of course they would not move. Second, all the advantages of having a denser city with fewer cars, less pollution, and less congestion will be lost. Thus rent controls significantly add to the diseconomies endured by city residents, at least in this case. Finally, by masking real market adjustments, rent controls will make it difficult to plan for public projects and will almost certainly result in more long-run mistakes than would have been made had the market been allowed to pass along appropriate signals.

There are, of course, policies other than rent controls that could significantly frustrate the adjustment to equilibrium. One such policy would be inappropriate

zoning regulations. In Chapter 3 it was argued that with rising gasoline prices some firms may wish to relocate in the suburbs, perhaps to take advantage of a ready labour supply, to reduce transportation costs for inputs and output, or to take advantage of lower rents. Such a relocation could be beneficial to urban consumers for a number of reasons: if the move is profitable it would tend to lower product price; the move would substantially reduce commuting costs for workers in the area; and the move away from the city would reduce congestion and pollution and would put downward pressure on CBD rents. It should also be noted that this argument depends only on the fact that gasoline prices have risen, not on the assumption that $t(u)$ has risen.

POLICY ISSUES

A good deal of attention has already been paid, both in the previous section of this chapter and earlier in the study, to types of policy on which this analysis can be brought to bear, so that here only a brief description of some of the more important issues is presented. As was mentioned above, the principal objective is to compare policy options for the two polar cases described earlier: the case where all adjustments occur through $t(u)$, the commuting cost, and the case where substitution and technological progress in the automobile industry succeed in completely offsetting the increase in petroleum prices.

Perhaps the principal activity of urban governments is the provision of a transportation facility; so it would seem appropriate to begin with this area. The fundamental issue, of course, is how an urban area should plan for future transportation needs when faced with significant increases in gasoline prices. With all adjustments in $t(u)$ it was dramatically illustrated in Chapter 6 that substantial increases in rents and in urban density near the CBD could be expected. If policy-makers expect such a result, the pressure on providing more and better roads will be considerably lessened, although one would expect an increase in the demand for bus and other urban transit facilities.

With all adjustments through substitution and technology there will, of course, be insignificant effects on rents and densities, since there will be no pressure on households to locate closer to the CBD. There will, nevertheless, be effects on the transportation facilities and implications for public policy. Although distances travelled will be the same, fewer cars will be used (some commuters changing to buses, etc.) and the cars that are driven will be smaller and lighter. Thus both congestion and wear and tear on roadways will be reduced. Thus, as in the previous case, less expenditure on roadways but more on public transit will be required than would have been the case without such gasoline price increases, although here the effects will not be as great. It is also of

interest that in both situations there are additional benefits of less congestion and less pollution. Note finally, however, that in both situations no growth in urban population has been assumed.

The effects on the transportation network will be reinforced by the effects that gasoline price increases will have on industrial location, and these changes in location will occur, whichever of the two scenarios above applies. With higher transportation costs one would expect some industries to find it profitable to locate in the suburbs, which would further reduce demand for roadways. In this case there will also be a reduction in demand for public transit, since fewer workers will commute to the CBD. Again, there will be beneficial effects on congestion and pollution.

Now consider the provision of public facilities such as parks, schools, and hospitals. Here the appropriate policies will clearly be different in the two cases. For increases in travel costs the higher densities near the CBD will suggest more parks in the area. Current policies of retiring old schools in the core area and building new ones in the suburbs will be just the opposite of what is required. For the substitution and technology alternative there will be no adjustment in household location and thus no change in the demand for schools and parks. Industrial relocation, because it is not generally assumed to affect the location of households, will have no appreciable influence in either case.

Urban governments provide all kinds of other services to households as well, ranging from garbage pick-up and snow removal to social services and welfare. For most of these services, since they tend to be related to place of residence rather than place of work, the effects for the two scenarios are quite clear: costs will tend to be less with higher densities.

Other policies, such as rent control and certain kinds of zoning, affect adjustment to equilibrium rather than being affected themselves by energy price increases. Such policies, particularly rent control, are presumably initiated for purposes of redistributing income and thus do not belong to the class of policies that would generally be seen to be within the realm of urban governments.

One final policy deserving of mention is the practice of assessing land for tax purposes on the basis of improvements rather than on the basis of the value of the land itself. Again, this is not a policy designed to correct market failure, and it influences adjustment rather than being influenced by gasoline price increases. It has effects not unlike very restrictive zoning, however, because essentially it allows and indeed encourages land-owners to make very socially inefficient use of property, particularly undeveloped land. By taxing improvements rather than the land itself, it discourages demolition and rebuilding and allows speculators to hold land off the market at very low cost. Both tend to reduce the speed of adjustment to the new equilibrium.

CONCLUSIONS

A summary for the entire study had been planned, but it was decided that, since the basic issues 'had been so much with us' throughout, further repetition would be neither necessary nor desirable. But while the reader is spared a summary, avoiding the authors' personal views concerning the probable effects of petroleum price increases on urban structure can be avoided only by reading no farther. It must be stressed, however, that these following few guesses simply represent personal weightings of the probabilities of all the events described. Those who have read this far will be in an equally informed position to make predictions of their own.

First, it seems likely that the major petroleum price increases have already occurred. The combination of reductions in demand, increases in supply, and the development of substitute fuel sources could very well preclude any major price rises in the foreseeable future. This seems particularly true for the short run, when the real price of petroleum may even fall. The situation is complicated in Canada, of course, because of federal oil policy; but at least for gasoline, provincial and federal taxes have succeeded in raising prices to close to U.S. levels.

At the same time it seems likely that technological progress will continue to improve the efficiency of automobiles, and one could even predict significant technological breakthroughs in other fuel sources such as electricity, hydrogen, or methane. Of course any such breakthroughs will put further downward pressure on the price of petroleum.

When he is faced with higher gasoline prices, the evidence very strongly suggests that the consumer will switch to more energy-efficient modes of transport, particularly to more efficient automobiles. At the same time the importance of income in both the demand for automobiles and the demand for housing (or spaces) suggests that in the longer run the trend for households to demand living space in less densely populated areas will continue.

These considerations strongly suggest that gasoline price increases will have only minor effects on the structure of cities. From the production side, petroleum price increases seem likely to speed up the shift of industry to the suburbs. The overall effects of increases in prices of other petroleum products such as heating oil and petroleum as an input to production are difficult to determine but probably are not of major importance. In summary, then, the overall long-run consequences of petroleum price increases for urban structure are likely to be small.

There will, of course, be some effects, at least in the short run. Many individuals, particularly the less well-to-do, have no substitution possibilities open to them. They may already have the most efficient car or may have no car

at all. There will undoubtedly be pressure on such individuals to move closer to their place of employment. Furthermore some individuals simply prefer the downtown area and may willingly give up larger suburban space to move nearer to the CBD. This trend will put pressure on existing residential space and will increase rents and property values. It is not clear how much of the recent housing price increase in central cities can be attributed to such effects, but certainly a portion of it can. Indeed, it seems clear that the major impact of increasing petroleum prices will be increases in rents and property values in the downtown areas of major urban communities.

Perhaps one should end on a positive note. From the point of view of urban residents gasoline prices have traditionally been much too low. The effect of these prices has been the overuse of automobiles and the production of far too much congestion and pollution. Whatever the response of consumers to higher gasoline prices – and of course all must respond in some way – the long-run consequences for the central city may well be desirable, relative at least to what would have happened otherwise. Pollution and congestion in all likelihood will be reduced, and the central city will be a more desirable place in which to live.

APPENDICES

APPENDIX A

Derivation of Mills's model

Define $X_i(u)$ as the quantity of X_i produced at a distance u from the city centre, assumed to be the export facility. The production technology is of the Leontief variety, and can be written as

$$X_i(u) = a_i L_i(u), \qquad i = 1, 2, \tag{A1}$$

where $L_i(u)$ is the amount of land used to produce X_i at a distance u from the CBD and a_i is the input-output coefficient and represents the ouput per acre of commodity i. It is further assumed that each worker requires one unit of X_2, housing services, and the units of X_1 are chosen so that each worker produces one unit of X_1. Thus the quantities of X_1, X_2 and the labour supply are all equal. ϕ radians of land are assumed available for the production of X_1 and X_2, and all land at each u in the urban area is assumed used for production of either X_1 or X_2. Thus,

$$L_1(u) + L_2(u) = \phi u. \tag{A2}$$

Land to a distance u is used in production, and given the equality of X_1 and X_2 one can write

$$\int_0^{\bar{u}} X_1(u)\,du = \int_0^{\bar{u}} X_2(u)\,du = X. \tag{A3}$$

One can solve equations (A1), (A2), and (A3) to obtain

$$\bar{u} = [2(a_1 + a_2)X / a_1 a_2 \phi]^{1/2} \tag{A4}$$

Thus $\bar{u}$ gives the radius of the city.

Mills then defines two different allocations: the segregated and the integrated. By the segregated allocation the X_1 industry is allocated as much land as is required near the city centre and the housing sector uses land on the outer edge of the city. By the integrated allocation both housing and production of X_1 are

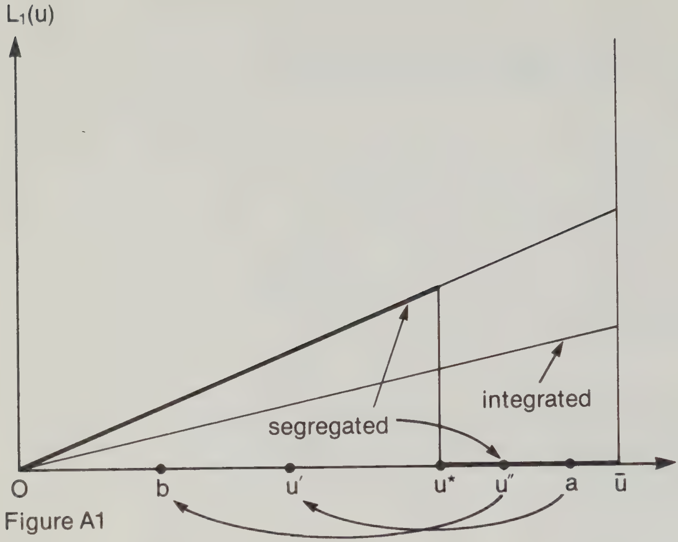


Figure A1

distributed evenly throughout the urban area. In the segregated allocation the transportation cost for X_1 is minimized, but there will be transportation costs for labour. By the integrated solution transportation costs for workers will be zero but transportation for the export good will be higher than under the segregated solution. These two allocations are shown in Figure A1, where O is the CBD or point of export, and where $L_1(u)$ is measured vertically and distance is measured horizontally. Under the segregated allocation X_1 uses all the land to u^* and all housing is between u^* and $\bar{u}$. Under the integrated solution both X_1 and X_2 are distributed evenly between O and $\bar{u}$.

Mills argues that because of the linearity of the model, either the segregated or the integrated solutions will be optimal, and that no other allocations can minimize total transport costs. The next task is to demonstrate this proposition and to derive the conditions that will determine which of the two allocations is to be preferred. Mills assumes that initially the segregated allocation prevails. An acre of land at u', where $0<u'<u^*$, is then chosen on which a_1 units of X_1 are produced. Another acre at u'', $u^*<u''<\bar{u}$, is found on which a_2 units of X_2 are produced. The points u' and u'' are chosen 'so that all the workers employed on the acre at u' live further from the city center than u'', and so that all the workers residing on the acre of u'' work closer to the city center than u'' (Mills, 1972, 87). Mills further claims that 'Two such points certainly exist.' Then $\Delta u = u'' - u' > 0$ is defined as the distance between the two points.

A reallocation of the production of the a_1 units of X_1 from u' to u'', and of the a_2 of X_2 from u'' to u', is then considered. With t_1 and t_2 as the cost per mile of transporting x_1 and workers, respectively, the increased cost of transporting X_1 associated with the reallocation will be $t_1 a_1 \Delta u$. The decrease in commuting costs will be $t_2 a_2 \Delta u + t_2 a_1 \Delta u$. Thus total transportation cost changes are

$$\Delta u(t_1 a_1 - t_2 a_2 - t_2 a_1). \tag{A5}$$

The reallocation will decrease transportation costs if and only if (A5) is negative. This condition can be rewritten as

$$(t_1 - t_2) / t_2 < a_2 / a_1. \tag{A6}$$

Thus if this inequality holds, the reallocation towards the integrated solution will reduce transportation costs and should therefore be undertaken. This, Mills argues, will ultimately lead to the full integrated solution. Conversely, if in place of (A6) one has

$$(t_1 - t_2) / t_2 > a_2 / a_1, \tag{A7}$$

then the segregated solution will be optimal. Should the two sides of (A7) be equal, any allocation is optimal as long as crosshauling is not permitted.[1]

Since all elements of (A6) are positive, (A6) will clearly hold if $t_2 > t_1$; that is, if the cost of transportation for a worker is larger than the cost of transporting the quantity of output that one worker produces. In such a case one would avoid transporting workers by employing the integrated solution. Of course the integrated solution may be optimal even if $t_1 > t_2$, as long as a_2 is sufficiently large relative to a_1.

It would also seem that the conditions imposed by Mills to demonstrate the optimality of either the segregated or the integrated allocation are rather more restrictive than suggested.[2] In Figure A1 u' and u'' satisfy Mills's conditions if the workers employed at u' live at a and if the householders at u'' work at b. Consider Figure A2 where it is assumed that a pie-shaped section of the city has been defined where each of the four regions I to IV in the production sector is one acre in area, and where each of the four residential areas 1 to 4 is also an acre in size. Now suppose the residents in area 1 work in region IV, those in area 2 work in III, and so on, as shown. It is easy to see that there do not exist two points u' and u''

1 Crosshauling exists if a worker lives between the CBD and his place of employment. If this were the case, the production of X_1 and X_2 could be switched and a savings in transport costs would be realized.

2 Essentially the same point is made by Waymire and Waymire (1980).

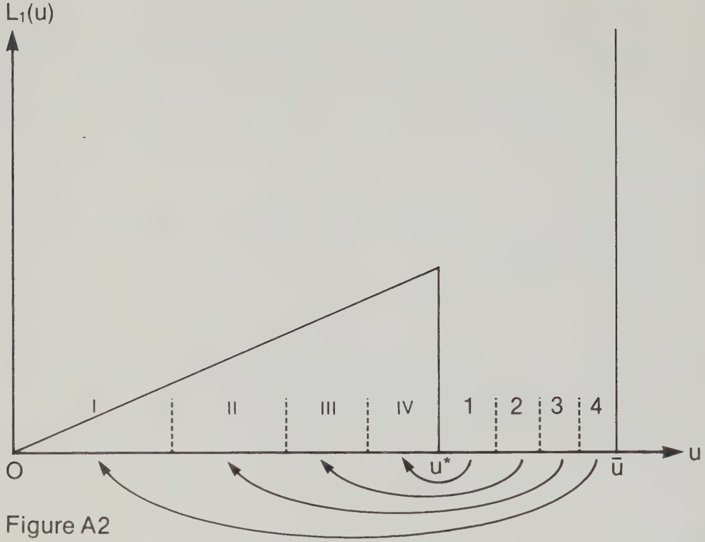


Figure A2

such that all workers employed on u' live farther away than u'' and where the residents at u'' work closer to the CBD than u'. It does not seem, then, that the two points required for Mills's proof will always exist. This, of course, does not prove that the theorem is incorrect, but just that the simple technique suggested by Mills is not adequate.

APPENDIX B

The mathematical formulation of substitution models

INTRODUCTION

The purpose of this appendix is to provide a somewhat more formal treatment of the models discussed in Chapter 5 and to provide the algebraic formulations of the specific models used for the policy simulations in Chapter 6. The order of presentation follows that of Chapter 5, and the only model that is included here but not found in Chapters 5 or 6 is the basic Muth model, which has been included in the third section to allow easy comparison with the other models in the chapter.

SUBSTITUTION BY PRODUCERS

Substitution decisions by producers in the face of energy cost increases are fairly straightforward to describe, since only simple cost minimization is involved. For example, consider a producer who must move a load, θ, a distance u. Suppose the combinations of capital (K), labour (L), and gasoline (G) that can accomplish this task can be described by the implicit equation

$$f(K, L, G) + 0, \tag{B1}$$

that is, combinations of (K, L, G) that solve this equation will accomplish the task of moving the load θ distance u. For example, the capital variable might represent different modes of transit and the labour variable both direct labour use and time. A producer seeking to find the least-cost method of transit would minimize his costs, $P_K K + P_L L + P_G G$, subject to the condition that the combination of (K, L, G) chosen would satisfy (B1). If there is substitutability between G and (K, L), then a reduction in G can be compensated by a change in (K, L) so that

(B1) is still satisfied. If such substitutability is possible, an increase in the price of gasoline, P_G, will generally lead to a substitution towards less gasoline used.

What implications does this have for the travel cost function? Consider a simple (but not completely unrealistic) travel technology in which the per mile cost of transporting a load θ is independent of the number of miles the load is to be transported. Let k, l, g be the cost minimizing quantities of (K, L, G) required to transport load θ one mile for prices P_K, P_L, P_G. Then the costs of transporting load θ a distance of u miles is

$$[P_K k + P_L l + P_G g]u = tu, \tag{B2}$$

where $[P_K k + P_L l + P_G g] = t$ is the cost per mile of transport. If the combination (k, l, g) cannot be changed, it is easily seen that the percentage change in t brought about by a 1 per cent increase P_G is approximately $[P_G g/t]$, that is, gasoline costs as a percentage of total costs. Thus, for example, if gasoline costs represent 30 per cent of total transport costs, a 1 per cent increase in the price of gasoline will increase transport costs by 0.3 per cent. But if substitution is possible, so that capital and labour can be substituted for gasoline, $[P_G g/t]$ is strictly an upper bound for the effect of an increase in gas prices on transport costs. In the short run it may not be profitable to do much substitution (e.g., a producer will generally have some short-run commitment to the model of transit). However, in the long run substantial substitution could take place in the face of sharply increased energy costs. Some of the evidence relating to actual substitution behaviour is summarized in Chapter 6.

SUBSTITUTION BY CONSUMERS

As indicated earlier in this appendix, modelling substitution by consumers is more difficult than modelling substitution by producers, since consumer preferences play a critical role in the choice of the type and extent of substitution. In this section of the appendix we shall consider some simple models of consumer substitution which highlight the major forms of substitution available.

Substitution in the production of transportation

It has been argued that the principal substitution possibilities open to consumers will be demand related and will involve either the evaluation of the services of various modes of travel or the evaluation of leisure time. It is also possible that there will be substitution possibilities in the consumers' production of transportation, substitution possibilities similar to those open to producers. To highlight these effects it is assumed in this section that the choice of travel method or mode

does not affect consumer preferences. Although this is not a realistic assumption, it does permit some insights into how such substitution possibilities modify the relationship between energy costs and urban structure. Later in this section we shall explicitly consider models in which consumer preferences play a central role.

Denote by m the miles covered per gallon (mpg) and suppose consumers can choose among modes that vary with respect to m. Assume, however, that the attribute m does not directly affect consumer well-being. Then a consumer's budget constraint in the simple residential location model can be written

$$y = x + r(u)q + p(m)\,m + (p_g/m)u + c, \tag{B3}$$

where $p(m)$ is the price of a mode of travel that attains an mpg of m, and c is the cost of a 'basic' automobile, assumed constant for all m. Now $p(m)$ could have two interpretations, depending on the method by which m is to be increased. One method is to purchase (rent) a more efficient (higher m) mode of travel. Although smaller, higher m, automobiles are often less expensive than larger, higher m, automobiles, the higher m in smaller automobiles comes at the expense of less room and other attributes provided by larger automobiles. Interpreted this way it seems reasonable to suppose that purchasing higher m incurs greater costs (in forgone other attributes). Another interpretation of $p(m)$ comes from the observation that m can to some extent be increased by travelling more slowly, so that $p(m)$ could be interpreted as the *time cost* of achieving an mpg of m. Since m, by assumption, does not enter the consumer's utility function, a consumer located at u will choose m so as to minimize travel costs, $p(m)m + (p_g/m)u$.

For simplicity, consider the case $p(m) = p_m$; that is, that in which the price per unit of m is constant. Then it can be shown that the cost minimizing choice of m is given by the equation

$$m = (p_g u/p_m)^{1/2}, \tag{B4}$$

and that minimized total costs, $t(u)$, can be written

$$t(u) = 2(p_g p_m u)^{1/2} + c. \tag{B5}$$

From (B5) we see that an increase in p_g to kp_g $(k > 1)$ increases travel costs from $t(u)$ to $k^{1/2}t(u)$.

The model of this section, although extremely simple, does illustrate one of the central propositions arising from the possibility of substitution away from gasoline. This proposition is that, when substitution possibilities exist, there is no longer a one-for-one relationship between the price of gasoline and travel

costs, and, in fact, the change in travel costs will be less than the change in gasoline prices. Since it is the travel cost function that determines urban structure, substitution possibilities temper the effects of increases in gasoline prices on urban structure.

Substitution to energy-efficient automobiles

This section will develop several models explicitly including automobile services in the utility function and thus permits substitution to more efficient automobiles. In Chapter 5 it was argued that the traditional Muth journey-to-work model does not permit the consideration of such a substitution; so that the model presented here can be easily compared to the more traditional approach, the Muth model is summarized first.

Muth (1969) assumes that consumers have utility functions defined over q, housing services, and x, all other goods. This function is written

$$u = u(x, q). \tag{B6}$$

The budget constraint facing individual households is

$$g = y - x - p_q\,(u)\,q - t(u, y), \tag{B7}$$

where y is household disposable income, $p_q(u)$ is the price of housing services, written as a function of distance u, and t is the cost of the journey-to-work by the head of the household. The price of x is set equal to unity. To maximize one forms the Lagrangian expression

$$L = u - \lambda g \tag{B8}$$

and sets the partial derivatives with respect to x, q, u, and λ equal to zero. For the partial derivative with respect to u one obtains

$$-q(\partial P_q(u)/\partial u) = \partial t/\partial u. \tag{B9}$$

The left-hand side is the product of the quantity of housing and the slope of rent function and is what was called Q in Chapter 4. The right-hand side is the extra cost of travel associated with moving another distance unit from the CBD or, in other words, the slope of the total travel cost function. This is the T of Chapter 4.

From (B6) and (B7) it can be seen that the effect on households of an increase in t (in this case as a result of higher gasoline prices) comes only through the budget constraint. There is no way in this model of considering a choice among different kinds of automobiles, since the services of automobiles nowhere appear. In order to permit a consideration of this kind of substitution we now turn to models that specifically include the services provided by automobiles.

In this model the individual commuter is assumed to have a utility function defined over housing services (q), other goods (x), and the services of an automobile (z). Commodity x is taken as the numeraire, and $p_q(u)$ and p_a are the prices of q and z, respectively. The price of housing services is assumed to be a decreasing function of the distance (u) from the CBD. Consumer's disposable income is assumed to be allocated among housing service, automobile services, other goods, and travel. The expenditure on travel is the cost per mile (c) multiplied by distance. The cost per mile is assumed to be a function of the services of automobiles and the price of gasoline.

There is nothing unusual in this formulation except for the specification of travel costs. The average cost per mile is written as a function of automobile services to reflect the fact that the higher the level of services required is, that is, the more the space, comfort, speed, and power required are, the larger the cost of operating the automobile per mile travelled will be.

Formulating the problem algebraically, we assume that individuals maximize utility

$$U = U(u, q, z), \tag{B10}$$

subject to the budget constraint

$$g = y - x - p_q(u)q - p_z z - uc(a, p_g). \tag{B11}$$

To maximize one forms the Lagrangian expression

$$L = U - \lambda g \tag{B12}$$

and sets the partial derivatives with respect to the variables x, q, z, u, and λ equal to zero. Again the partial derivative with respect to u is of interest, and we obtain as a first-order condition

$$-q\ \partial p_q/\partial u = c(z, p_g). \tag{B13}$$

This equilibrium condition is illustrated in Figure 5 in Chapter 5 and discussed there. It is similar to Figure 3 in Chapter 4, except that, since total cost of travel has been assumed proportional to distance, the marginal cost function is a constant. As before $-qp'$ is downward sloping because of the shape of the rent function.

To get a more explicit idea of how substitution towards more energy-efficient automobiles will affect the journey-to-work model we shall now consider a model with an explicit simple form of substitution. In this model it is assumed that substitution takes the form of changing to higher mpg automobiles and that

there is a direct relationship between the cost of automobiles and mpg and between consumer preferences and mpg.

It will be assumed that the utility function for space (q), other goods (x), and mpg (m) can be written

$$U(x, q, m) = Ax^{(1-\beta)} q^{\beta} m^{-\gamma}, \tag{B14}$$

where m is the mpg attained. What is being assumed here is that modes of travel with higher m are less pleasurable (e.g., smaller cars are less roomy, less safe, etc., other things being equal). The travel cost function will be written

$$t(u, m) = c + p(m)m + (p_g/m)u. \tag{B15}$$

Other things being equal, smaller automobiles (higher m) would be expected to be less expensive, so that $p(m)$ would be expected to decrease with m. In the model of Section 2a of Chapter 6, p_m proxied reductions in utility so that p_m did not fall with m. For computational simplicity it will be assumed that $p(m) = p_m / m^2$. Using this specification of $p(m)$, it can be shown that $m(u)$, the mpg chosen by a resident at u, is

$$m(u) = (1 + \gamma)(p_m + p_g u)/\gamma(y - c). \tag{B16}$$

As would be expected, residents living at a greater distance from the CBD choose modes of travel with higher mpg.

Substituting (B16) into (B15), $t(u)$ (the travel cost function that incorporates optimal substitution by consumers) becomes

$$t(u) = (\gamma y + c)/(1 + \gamma). \tag{B17}$$

Notice now that total travel costs do not vary with distance! However, residents living further from the CBD substitute towards higher mpg modes of transportation, which reduces their utility, other things being equal. Therefore, it is still the case that the rent gradient must slope down in equilibrium so that residents further from the CBD can consume more land, counteracting the effect on utility of having a higher m.

Also, notice that the travel cost function, $t(u)$, is independent of the price of gasoline, p_G. In this model consumers substitute so that the amount spent on travel a distance u is a constant, independent of p_G, so that the amount of income remaining to be spent on space and other goods is independent of p_G. Therefore, an increase in p_G has no effect on urban structure in this model! The only effect in the model is that residents change to higher mpg automobiles and reduce their use of gasoline. Of course the residents are made worse off from an increase in p_G, since increases in m reduce their well-being, given their utility function (B14).

The model of this section is not realistic, and naturally it would not be expected that substitution towards higher mpg automobiles would completely negate the need for urban structure to adjust to increases in gasoline prices. None the less, this model should make it clear that alternative modes of substitution can greatly temper the need for urban structure to adjust, even in the long run, when it is possible for urban structure to adjust fully.

Time-intensive substitution

One way that commuters can substitute in the face of increases in gasoline prices is to move towards more time-intensive, less gasoline-intensive travel. For example, a commuter with highway travel as part of his commuter trip could reduce his highway speed. Other examples include modal switches to public transit or car pooling. Time costs of travel are a very important component of total travel costs. For example, the average commuter trip in Toronto is 10.9 miles and takes twenty-three minutes (Transport Canada, 1979). At 18 cents / mile, the direct travel costs are \$1.96, while the time costs, if time is valued at \$3.00 / hour, are \$1.15; so that time costs are certainly not negligible relative to direct travel costs. As direct travel costs increase relative to time travel costs (e.g., because of an increase in gasoline prices), it would be expected that commuters would substitute towards more time-intensive travel. In what follows, simple models incorporating the possibility of such a trade-off will be sketched.

This section will begin with a simple model of substitution to alternative modes. In this model it is assumed that the individual has the options of driving his car to work or taking the bus. The utility function is defined over the three variables x, q, and leisure (l). In the initial situation the commuter drives his car to work because the extra cost in terms of time spent in taking the bus is too high relative to the cost of operating an automobile. Again it is assumed that total travel cost is the product of distance and the average cost per mile, but now average cost is considered to be a function of speed (s) and the price of gasoline. More formally the problem is to maximize

$$U = U(x, q, l) \tag{B18}$$

subject to

$$g = y - x - p_q(u) \cdot q - u \cdot c(s, p_g). \tag{B19}$$

We also have that

$$s = u/t, \tag{B20}$$

where t is time. The total time available for travel and leisure activity is defined to be T_0, and thus

$$T_0 = l + z. \tag{B21}$$

Substitution of (B21) and (B20) into (B19) yields

$$g = y - x - p_q(u)\, q - uc\,(u/(T_0 - l), p_g). \tag{B22}$$

Forming the Lagrangian expression as before and setting the partial derivatives with respect to the variables x, q, l, u, and λ equal to zero, one obtains, for the partial derivative with respect to u,

$$-q\, \partial p_q/\partial u = u\,(dc/ds)/z + c \tag{B23}$$

or

$$-q\, \partial p_q/\partial u = c\,[(dc/ds \cdot s/c) + 1], \tag{B24}$$

which can be written

$$-qp_q' = c[\epsilon + 1]. \tag{B25}$$

In (B25) ϵ is a kind of speed elasticity of average cost, and it is clearly positive. It is not obvious how it will be affected by distance, so it will be assumed independent of u. Thus the diagram for (B25) is essentially the same as Figure 3. The effects of increases in p_g, however, are likely to be quite different from those of the section 'Substitution by producers.' The trade-off that the consumer must now make when p_g increases is between leisure and other commodities (x and q), and the empirical evidence suggests that consumers do place a high value on leisure. Furthermore the services of a house and leisure are complements, so that l and q would be expected to move together. In general, then, one would expect to find a significantly larger shift in the right-hand side of (B25) than in the right-hand side of (B13), the implication being that this model will lead to a somewhat larger effect on urban structure than the substitution to more energy-efficient automobiles did.

Now an explicit model of time-intensive substitution will be considered. Denote commuting time by τ and assume that a resident's utility function can be written

$$U(u, q, \tau) = A(x)^{(1-\beta)} q^{\beta} \tau^{-\gamma} \tag{B26}$$

Now the relationship between commuting time and travel costs must be modelled. It will be assumed that slower travel incurs smaller (direct) travel costs. Let miles-per-minute (speed) be denoted mpm and gallons-per-minute be

denoted gpm. Then it is assumed that there is a positive relationship between mpm and gpm. Suppose, for example, that the relationship is

$$\text{gpm} = k(\text{mpm})^2. \tag{B27}$$

Then, since mpg = mpm/gpm,

$$\text{mpg} = [k \cdot \text{mpm}]^{-1}. \tag{B28}$$

Travel costs, $t(u)$, are simply

$$t(u) = (\text{mpg})^{-1}\, p_G u, \tag{B29}$$

and therefore

$$t(u) = (k \cdot \text{mpm})\, p_G u. \tag{B30}$$

Finally, mpm is simply u/τ, so that

$$t(u) = k p_G u^2/\tau. \tag{B31}$$

With preferences given by (B26) and travel cost function given by (B31), it is easily shown that residents choose τ so that

$$t(u) = \gamma y/(1+\gamma). \tag{B32}$$

Therefore, as in the previous model, travel costs are independent of distance and of the price of gasoline, so that the price of gasoline has no effect on urban structure. Again, this result should be interpreted simply as showing that substitution towards more time-intensive travel will temper the effects of increases in gasoline prices on urban structure, even in the long run.

APPENDIX C

Policy simulation models

This appendix sets out the model underlying the simulations presented in Chapter 6.

The utility function of the (identical) consumers is assumed to be Cobb-Douglas and will be written

$$U(x, q) = Ac^{1-\beta} q^{\beta}\,, \qquad A = (1 - \beta)^{1-\beta} \beta^{\beta}]^{-1}, \tag{C1}$$

with the budget constraint

$$y - x - r(u)q - t(u) = 0, \tag{C2}$$

The indirect utility function is

$$V(r(u), y - t(u)) = (y - t(u))\,[r(u)]^{-\beta}. \tag{C3}$$

The travel cost function, $t(u)$, is assumed to be of the simple form $t(u) = tu$.

Let the equilibrium (common) level of utility attained be denoted by $\bar{V}$. Then (C3) can be solved for the equilibrium rent gradient by setting $V(r(w, y) = \bar{V}$, which yields

$$r(u) = (\bar{V})^{-1/\beta} (y - tu)^{1/\beta}. \tag{C4}$$

A resident's demand for space at distance u, $q(u)$, can be written

$$q(u) = \beta\,(y - tu)/r(u). \tag{C5}$$

Let $n(u)$ be the number of households residing at distance u. Then, since $2\pi\theta(u)u\Delta u$ is the amount of land available for residential purposes in the ring of width Δu at distance u, the equality of the demand and supply for space at distance u can be written

$$n(u) = 2\pi\theta(u)u\,\Delta u/q(u). \tag{C6}$$

Hereafter it will be assumed (as in the simulations) that $\theta(u) = \theta$. Since the total number of households is N, equilibrium requires that

$$\int_0^{u^*} n(u)du = N. \tag{C7}$$

Let $\bar{r}$ be the opportunity rent on land. Then it must be the case that $r(u^*) = \bar{r}$. Substituting into (C4) gives

$$r(u) = [(y - tu)^{1/\beta} / (y - tu^*)^{1/\beta}]\bar{r}. \tag{C8}$$

Now, if (C8) is substituted into (C5), (C5) into (C6), and finally, (C6) into (C7), the equilibrium condition for the model can be written as

$$\frac{2\pi\theta\beta}{\bar{r}} \int_0^{u^*} (y - tu^*)^{1/\beta} (y - tu)^{1-1/\beta} du = N, \tag{C9}$$

which is an equation in one unknown (u^*). Let $\epsilon = (1 - tu^* / y)$; that is, ϵ is income net of travel costs as a proportion of total income at distance u^*. Then (C9) can be integrated and written in terms of ϵ:

$$\beta\epsilon^{-1/\beta} + \epsilon - (\beta + 1)\,[(Nt^2/2\pi\theta\bar{r}y) + 1] = 0. \tag{C10}$$

Equation (C10) can be solved for ϵ numerically, given values of β, N, t, θ $\bar{r}$ and y, and then u^* is easily derived, given the relationship between u^* and ϵ. With use of (C8), $r(u)$ is then quantified.

Now consider D, the total number of commuting miles driven. The total number of commuting miles driven per day by households residing at u is simply $2n(u)u$. It will be assumed that there are 250 commuting days per year, so the total number of miles driven per year by households at u is 500 $n(u)u$. Again, using (C5) and (C7) to express $n(u)$,

$$D = \frac{500(2\pi\theta\beta)}{\bar{r}} \int_0^{u^*} (y - tu^*)^{1/\beta} (y - tu)^{1-1/\beta} u\, du, \tag{C11}$$

which, given u^*, is easily integrated to obtain D.

Finally, the number of households living within four miles of the CBD, N_4, is simply

$$N_4 = \int_0^4 n(u)\, du. \tag{C12}$$

In the simulations rents are calculated per acre (there are 640 acres in a square mile). Since income is given on a yearly basis, travel costs must be calculated on a yearly basis. Therefore each mile of one-way commuting per day represents 500 miles of round-trip commuting per year (250 work days per year). For example, a commuting cost of 18 cents / mile becomes \$90 / (one way) mile per year.

SHORT-RUN MODEL

In the short-run model the city is assumed to start in a long-run equilibrium for the 1976 benchmark parameter values. The initial equilibrium lot sizes can then be computed from (C5) and the equilibrium rent gradient. In the short-run model it is assumed that after one of 1976 benchmark parameters changes (e.g., gasoline prices) a new short-run equilibrium is attained in which utilities of residents are again equalized. Consider a resident living at distance u on a lot of size $\hat{q}(u)$. Let $\hat{r}(u)$ be the (short-run) equilibrium rent for the lot $\hat{q}(u)$. Then a household residing on lot $\hat{q}(u)$ will have $(y - \hat{r}(u)\hat{q}(u) - tu^*)$ amount of income to spend on other goods. Let u and u' be two arbitrary distances. Then the short-run equilibrium rent gradient must be such that

$$U(y - \hat{r}(u)\hat{q}(u) - tu^*, \hat{q}(u)) = U(y - \hat{r}(u')\hat{q}(u') - tu', \hat{q}(u')). \tag{C13}$$

Let $V(r(u), y - tu)$ be the (common) indirect utility function for the residents. Then the short-run equilibrium utility, $\hat{V}$, is simply

$$V(\bar{r}, y - tu^*) = \hat{V}, \tag{C14}$$

where u^* is the initial equilibrium radius of the city, since there is vacant land at distance u^*, so that a resident could rent a lot at u^* at rent r. Therefore, the short-run equilibrium rent gradient, $\hat{r}(u)$, is given the solution of

$$U(y - \hat{r}(u)\hat{q}(u) - t\hat{u}, \hat{q}(u)) = V(\bar{r}, y - tu^*), \tag{C15}$$

where $\hat{q}(u)$ is given by the initial equilibrium.

Given the Cobb-Douglas preferences, (C15) can be written

$$A[y - r(u)q(u) - tu^*]^{1-\beta}[q(u)]^{\beta} = (y - tu^*)\bar{r}^{-\beta}. \tag{C16}$$

The rent on a newly created lot at distance u is given simply as the solution of the equation

$$V(r(u),\ y - tu) = (y - tu)[r(u)]^{-\beta} = \hat{V} \tag{C17}$$

for $r(u)$. Then, the (short-run) equilibrium lot size for a new lot at distance u, $q(u)$, is simply

$$q(u) = \beta(y - tu)/r(u). \tag{C18}$$

A MODEL WITH SUBSTITUTION POSSIBILITIES

The models considered thus far in this appendix do not allow any substitution response to increases in gasoline prices other than in urban structure and

residential real estate values. This section will consider a simple model that allows other forms of substitution. As will be shown here, the addition of other forms of substitution modifies the extent to which urban structure and urban real estate values must adjust to increases in gasoline prices.

In the simple model considered in this section the existence of other forms of substitution has two basic effects. First, it changes the form of the travel cost function $t(u)$. Secondly, it changes the relationship between the price of gasoline and the travel cost function $t(u)$. These effects result in a different urban structure for a given price of gasoline (from the simple model with $t(u) = tu$), and in a different response of urban structure to changes in the price of gasoline.

In Appendix B a simple model was presented in which a trade-off between miles per gallon (mpg) and cost of achieving mpg was sketched. This model will be developed further here. It will be assumed that travel costs can be written

$$t(u) = c + p(m)m + (p_g/m)u \tag{C19}$$

where m is mpg, $p(m)$ the 'price' of attaining m, p_g the price of gasoline, and c the 'basic' costs of an automobile. A critical simplifying assumption of this model is that m does not enter a resident's utility function, which is unrealistic. However, this model has the great advantage of being computationally simple, so it is worth considering simply as a contrast to the simple models of the previous section. Later, more realistic models will be discussed.

If the travel cost function is as in (C19) and m (or other substitution parameters) does not enter a resident's utility function (C1), a resident will choose a mode of travel that yields an m that minimizes (C19). For simplicity assume that $p(m) = p_m$. Then it can be shown that the level of m chosen by a resident at u is

$$m(u) = [(p_g/p_m)u]^{1/2}, \tag{C20}$$

and the travel cost function, $t(u)$, is then

$$t(u) = c + 2\,[p_g p_m u]^{1/2}. \tag{C21}$$

In terms of the simple journey-to-work model, the substitution possibilities incorporated in (C19) change the model by replacing $t(u) = tu$ by (C21). What are the implications of (C20) and (C21)? According to (C11), residents who live farther from the CBD use modes of transit yielding higher m. This modal choice, of course, is intuitively plausible. Residents living farther from the CBD bear higher costs of travel, other things being equal, and thus it is in their interest to substitute towards more efficient (higher m), higher fixed-cost (higher $p_m m$) modes of travel.

The other important implication of (C19) is that travel costs, $t(u)$, no longer vary linearly with distance, but form a concave curve. This means that the

marginal travel costs of distance (how travel costs vary with distance) are no longer constant, but instead are decreasing. There are a number of ways in which to explain how (C19) affects urban structure relative to the no-substitution model. Assume that residents' incomes and preferences are the same (preferences given by (C1)) and that the opportunity cost of land, $\bar{r}$, is the same in the two models. Then differences in the two models will depend on the values of t, p_m, p_g, and c. It is difficult to quantify p_m and c, so consider a comparison in which c and p_m are such that residents in a city with a travel cost function (C19) attain the same level of utility as those in a city with the simple travel cost function $t(u) = tu$.

Let $r(u)$ be the rent gradient in the no-substitution model, and $\hat{r}(u)$ be the rent gradient in the model with $t(u)$ given by (C19). Then, assuming identical utilities, the relationship between $r(u)$ and $r(u)$ can be written

$$\hat{r}(u)/r(u) = [y - c - 2(p_g p_m u)^{1/2}]^{1/\beta} / (y - tu)^{1/\beta}, \tag{C22}$$

where β is the proportion of net (after travel costs) income spent on land (from (C1)).

Let $d(u)$ and $\hat{d}(u)$ be the residential densities for the two models at distance u. Then it can be shown (again assuming equal utilities) that

$$\hat{d}(u)/d(u) = [y - c - 2(p_g p_m u)^{1/2}]^{\alpha/\beta} / (y - tu)^{\alpha/\beta}, \tag{C23}$$

where $\alpha = 1 - \beta$.

In Figures C1 and C2 the relationship between the rent gradients (C22) and that between the density gradients (C15) in the two models are depicted.

As drawn in Figure C1, the equilibrium city with travel cost function given by (C19) is larger than the city with $t(u) = tu$ (i.e., $\hat{u}^* > u^*$). This result depends on c and p_m's being small enough relative to t. If c and p_m are large enough, the curve $\hat{r}(u)$ will lie below $r(u)$ to the left of u^*, resulting in $\hat{u}^* < u^*$. As another comparison, if it happened that t, c, and p_m were such that the two travel cost functions were equal at u^* $[tu^* = c + 2(p_m p_g u^*)^{1/2}]$, the two cities would be equal in size, but density would be higher at each distance in the no-substitution model. This would also mean, of course, that the population in the model with $t(u) = tu$ would be larger.

Now consider how increases in p_g affect the two models. In the no-substitution model write $t = (\alpha + p_g/\bar{m})$ where α is the non-gasoline cost per mile. Then an increase in the price of gasoline of Δp_g increases total travel costs by commuting from distance u by $\Delta p_g u / \bar{m}$, which can be written $(p_g u/\bar{m})\Delta p_g/p_g$; that is, total gasoline travel costs times the percentage change in gasoline prices. In the model with travel costs given by (C21), a small increase in p_g of Δp_g increases total travel costs at $\bar{u}$ by $[(p_g p_m \bar{u})^{1/2}]$ $(\Delta p_g/p_g)$, which again is simply total gasoline travel costs times the percentage change in gasoline prices. The parameter $\bar{m}$

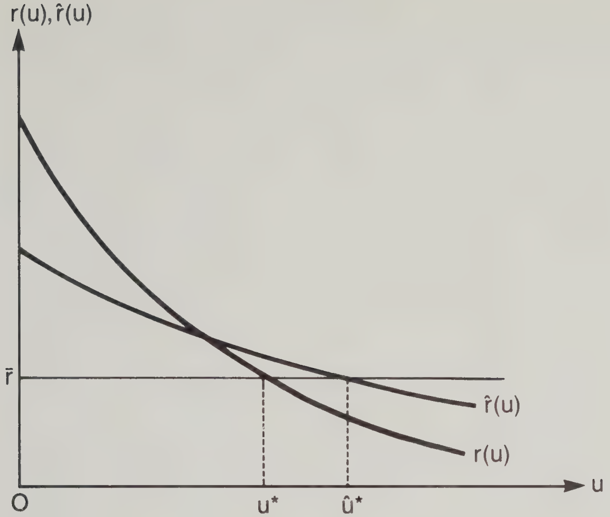


Figure C1

would presumably be interpreted as *average* mpg in the simple model. Therefore in comparing the two models an increase in p_g would shift up travel costs in the substitution model relatively more for small u and relatively less for large u than in the no-substitution model (since m is smaller for small u in the substitution model).

These effects, other things being equal, would tend to flatten out the new rent gradient resulting from an increase in p_g relative to the simulations presented earlier in Chapter 6. This means that there will be less pressure on the city to shrink and on rents near the CBD to rise when substitution possibilities exist. In summary, this simple model suggests that the ability to substitute towards less gasoline-intensive modes of travel will temper the effects of gasoline price increases on urban structure and residential real estate values.

What have we learned from our analysis of substitution possibilities? Recall that the travel cost function $t(u)$ is a critical determinant of urban structure. In particular, increases in travel costs will, other things being equal, adjust urban structure in a direction which, among other things, tends to economize on travel costs. The larger the change in travel costs, the more urban structure, to the extent it can, will adjust. Our analysis of substitution possibilities indicates that increases in gasoline prices (or other travel-related energy costs) are likely to encourage substitution to less gasoline-intensive methods or modes of travel. Thus, although an increase in the price of gasoline is likely to result in some increase in travel costs, $t(u)$, and marginal travel costs, so that rent and density

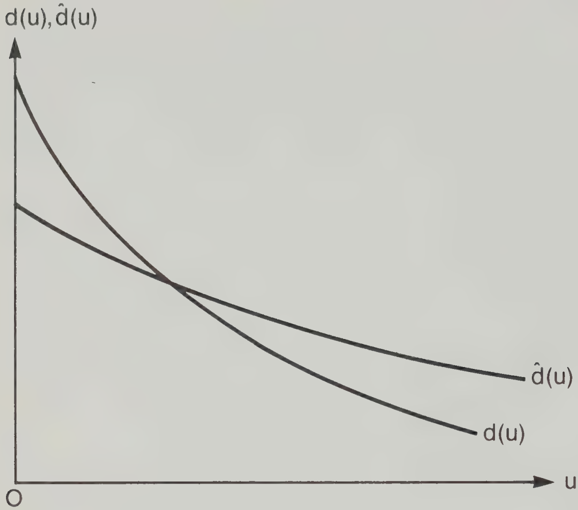


Figure C2

gradients are predicted to become steeper and urban areas smaller, substitution possibilities moderate the effects of energy price increases on travel costs and therefore on urban structure. Especially in the short run when existing urban structure predominates, other means of economizing on energy costs would be expected to predominate. In Chapter 7 empirical evidence is presented that suggests that the mandatory fuel efficiency standards imposed by the U.S. government may well offset the effects of gasoline price increases on the costs of automobile travel. Thus the combination of the various kinds of substitution and technological improvements in automobiles seems likely to produce very modest increases in travel costs. And while these results have been calculated for the U.S. economy, the close relationship that exists between the Canadian and the U.S. automobile industry suggests that these results will be relevant for Canada as well.

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27 An Economic Analysis of the Impact of Oil Prices on Urban Structure

JAMES R. MELVIN and DAVID T. SCHEFFMAN

This study examines ways in which residents of Canadian cities are affected by increases in petroleum prices. The authors apply economic models of residential and industrial location to determine the response of individuals and firms to higher oil prices in the short run and the long run. The short run effects include conservation of higher price petroleum products and reduction in other expenditures; the long run effects include movement closer to employment centres, changes in urban densities, rents, and house prices, and substitution of other forms of transit. The implications for municipal zoning, the provision of parks, the location of schools and other public facilities, and plans for road building and expressways are also considered.

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